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Final Report
Use of 1) Sensors and 2) Radio Frequency ID (RFID) for the National Children's Study

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Foreword

This report was prepared by RTI International for the U.S. Environmental Protection Agency (EPA) under Contract No. 68-D-02-069 as a deliverable under a work assignment to prepare issue papers examining the use of 1) sensors and 2) radio frequency ID (RFID) technology. This report identifies devices using these types of technologies and offers a preliminary assessment of the utility of these devices and their needs for development for future uses in the National Children's Study in four primary areas:

1. Measurement and analysis of health/medical characteristics
2. Measurement and analysis of exposure
3. Collection of questionnaire data
4. Networking of these devices

These technological areas were identified during the Workshop on Innovative Technologies for Remote Data Collection of Data for the National Children's Study in May 2003 as the most promising in terms of utility in support of the data collection efforts of the National Children's Study.

The information contained within this document was obtained through Web sites, research papers, and conversations with manufacturers and researchers around the world. This report is not a complete record of all details discussed, nor does it embellish what information was gathered, but it does provide a basic interpretation of the technology and assesses whether the gathered information seems reasonable. No devices or technology were evaluated firsthand. Devices and technology that seem promising would need to be obtained for more detailed analysis and field testing to determine its applicability to the National Children's Study.

Mention of trade names or commercial products does not constitute endorsement or recommendation for use. None of the statements herein represent analyses by or positions of the EPA.

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LIST OF ABBREVIATIONS

AF	Atrial Fibrillation
AME	Advance Medical Electronic Corporation
AMI	Ambulatory Monitoring, Inc.
BC	Black Carbon
CDMA	Code-Division Multiple Access
CMS	Chip Measurement System
CNN	Cable News Network
CO	Carbon Monoxide
DC	Direct Current
DoD	Department of Defense
EDR	Enhanced Data Rate
EMS	Environmental Monitoring System
EOFS	Environmental Observation and Forecasting Systems
EPA	U.S. Environmental Protection Agency
ESI	Environmental Sensors Inc.
ETS	environmental tobacco smoke
GSM	Global System for Mobile Communications
H2S	Hydrogen Sulfide
HR	Heart Rate
ICPMS	Inductively-Coupled Plasma Mass Spectrometry
iDEN	Integrated Digital Enhanced Network
M2M	Machine-to-Machine
MEMS	Micro-Electro-Mechanical Systems
NCS	National Children's Study
NIH	National Institutes of Health
NO	Nitrogen Oxide
NO2	Nitrogen Dioxide
O3	Ozone
OAS	Object Alarm System
OVM	Organic Vapor Monitor
PC	Personal Computer
PDA	Personal Digital Assistant
PM	Particulate Matter
ppm	Parts Per Million
RAE	RAE Systems Inc
RF	Radio Frequency
RFID	Radio Frequency Identification
RTI	RTI International
SIDS	Sudden Infant Death Syndrome
SMS	Short Message Service
SO2	Sulfur Dioxide

SpO2	oxygen saturation
SRDCorp	Sensors Research and Development Corporation
SSIM	Smart Sensors and Integrated Microsystems
TALE	Time/Activity/Location/Exertion-Level
TLV	Threshold Values
UPC	Universal Product Code
UWB	Ultrawideband
Wi-Fi™	Wireless Fidelity
WLAN	Wireless Local Area Networks
WPAN	Wireless Personal Area Networks
WWAN	Wireless Wide Area Network
XRF	X-Ray Fluorescence

EXECUTIVE SUMMARY

The National Children's Study (NCS) will examine the effects of environmental influences on the health and development of more than 100,000 children across the United States, following them from before birth until age 21. The goal of the study is to improve the health and well-being of children. In order to accomplish this goal, the NCS will need considerable information about the environment in which these children live and their physiologic responses. This paper explores modern technological approaches to obtaining such measurements in order to increase accuracy and to improve the ability to collect multiple (sometimes continuous) measures, while at the same time limiting the burden on participants.

The information in this paper will be used in the development of the study plan and protocol; at this time, it is unknown whether any such devices will be utilized in the study, but the NCS is committed to accurate measures of the environment while minimizing the burden to participants.

This paper stems from the report of the Workshop on Innovative Technologies for Remote Data Collection of Data for the National Children's Study, which was held on May 12 through 14, 2003 at the Hyatt Harborside Hotel in Boston, MA. Two promising technological areas for the NCS that emerged from this workshop were radio frequency identification (RFID) and sensors. This paper presents research on the scope of technology currently available within these two technological areas, as well as basic interpretation as to whether or not these technologies are mature enough to be implemented on a larger scale. Most of the technologies presented are currently available or, with modifications, could be available to be implemented in the NCS in the near- (within 12 to 18 months) to mid-term (18 months to 5 years). RTI International (RTI) had difficulty obtaining specific information about the long-term (5 years and beyond) research projects on which manufacturers and researchers were working, due to concerns of intellectual property and classified materials. By and large, technologies identified for the long term are presented only in abstract terms.

However, the technology that is currently available can provide a glimpse of what will become available in the future. Technology is a market-driven economy that is loosely run according to Moore's law—where the number of transistors (and hence memory/processing power) per square inch doubles roughly every 18 months. As such, lighter, faster, and more powerful devices will become available given the proper demand. For instance, Wal-Mart has required that its suppliers use RFID technology instead of the traditional UPC (bar codes) on its products, thus fueling an incredible advancement in RFID technology in recent years.

Technology could prove to be a critical component of the NCS. The overwhelming trend in technology is to move towards a ubiquitous environment where there are interconnected computing devices throughout one's environment. This trend is being brought about by a convergence of advanced electronics, particularly that of wireless technologies and the Internet. In the near future, ubiquitous computing devices (termed "smart devices"), which are not personal computers per se but very tiny (even microscopic) devices, that will be communicating through increasingly interconnected networks. These devices, either mobile or embedded, may be found in almost any type of object imaginable, including cars, tools, appliances, clothing, and various consumer goods. These smart devices will be able to maintain current information about a person's locations, the contexts in which they are being used, and relevant data about the users. Smart device research may ultimately lead to the creation of a system that is ubiquitously and unobtrusively embedded in the environment, completely connected, intuitive, effortlessly portable, and constantly available. Emerging technologies expected to prevail in the ubiquitous computing environment of the future include wearable computers, smart homes, and smart buildings. Within this type of data collection environment, it is possible that the NCS will be able to collect more data, more reliably, and do so with reduced participant burden.

Currently, however, there are major gaps in this technology as it applies to the NCS. Many of the NCS's monitoring needs are far beyond the reach of current sensor technology and would have to be implemented with standard collection and analysis techniques. Implementing useful technologies will require innovation, field testing, and close coordination and monitoring between manufacturers, researchers, and study subjects. Additionally, researchers may have to adapt their policies and procedures in order to fit the capabilities of the technology. For instance, if these technologies are used by the NCS, each should be thoroughly explained to the families and consent should be obtained for use. Further, the NCS would need to provide assurances that the data would be collected only for research purposes and that they would respect the confidentiality of the data and the privacy of the participants and their families. However, given the right mix of consumer demand, time, and efficiencies leading to reduced costs, the evolution of currently available technologies may make this ubiquitous computing environment more of a reality for the NCS and thus provide more/better data at reduced burden on the participant.

Editor's Note: ***Appendix A*** provides product information from manufacturers and researchers as identified by Web searches, recommendations, interviews, and journal articles for many of the products mentioned in this paper. In contrast, ***Appendix B*** provides information on different resources for RFID and sensor technology, including, but not limited to product information. Because Web pages change over time, ***Appendix C*** provides a printout of each Web page at the time they were referenced.

1.0 INTRODUCTION

Recent advancements in technology have provided new tools that researchers can use to collect data more easily and reduce participant burden. In what ways will this new technology impact researchers and participants? Imagine a scenario where a small child is playing outside of his home in rural Nebraska. He plays some catch with his father, plays in the sprinkler with his brother, and rests in the sun for a few hours with his new puppy. Now imagine that child can be constantly monitored for respiratory variables related to asthma throughout his day without any effect on his lifestyle or that of those around him. Every breath, every cough, every activity—even his sleep quality—can be continuously monitored. The child can be monitored because he is wearing a small physiological sensor embedded into his shirt. To him, this light-weight, machine-washable garment doesn't feel any different than the rest of his clothes, but there is a difference. Each day, a wireless chip in the shirt stores respiratory measurements collected throughout the day and transmits these data to a wireless receiver in his home. If the data are normal, they can, for example, be sent to doctors or researchers at a university in New York over the Internet for analysis, without the boy ever having to leave his Nebraska home. Or, if the receiver registers information constituting a medical emergency, this emergency could trigger an alarm, which would dispatch a message to the local hospital using cellular lines. This example illustrates how the interaction between sensor technology, radio frequency technology, wireless networks, telephone and cellular lines, and the Internet enables investigators to constantly monitor different aspects of the physical world without ever leaving their desks, and without intruding on the lives of those they are most interested in studying.

However, while the technology from this example is currently available, with advancements on current techniques and devices constantly being made, investigators should proceed cautiously. The applications of this technology sound promisingly relevant to the NCS, but investigators must carefully consider the strengths and limitations of the data collection environment, the data that are collected, and the sensors themselves before implementing these devices widely. Selecting the proper level of monitoring for the information obtained in the NCS is a task that can not be performed here. No one has considered monitoring body temperature on 100,000 subjects each minute for 20 years, a parameter that is technologically within reach today with minimal burden on the participant. Would that flood of data contain within its depths some real indications of health effects, particularly as seasons change, pollutant episodes sweep across an area, or viral infections spread across the nation? RTI has no way of judging, and so this paper presents descriptions of possibilities and project how they might be used.

Most of the contaminants that are currently the focus of the NCS do not present emergency health problems and do not require an emergency response. Because of the low concentrations of contaminants usually encountered, cumulative exposures are generally of greater concern than acute exposures, although acute exposures can trigger health responses such as asthma attacks. Sensors that give near real-time readings of contaminants are not particularly useful unless an acute response to the contaminant is expected. Sensors that measure physiological responses to contaminants accurately and selectively over periods of days to weeks would be more likely to provide dose (uptake) information without being burdensome.

The use of this type of sensor in the private home would also benefit from networking technology. Consider a routine urinalysis capability. An automated message could alert a family that it is time for a specimen to be collected. Urine could be introduced to an analyzer that performs tests, which requires multiple steps and several minutes or time but operates unattended and with minimal operator training. When the test is complete, the analyzer can use the network to transmit the results without intervention. If test results are not received within a reasonable length of time, a participant would be notified a second time or tagged for a personal follow up. This “smart” data collection scenario is relatively straightforward to implement and can be broken down into two main components: the sensors themselves and the networks with which they communicate. The sensors gather data about the physical world, and the networks help to relay this information to the end user.

2.0 SENSORS

The main function of a sensor is to detect some sort of physical stimulus—such as temperature, heart rate, or carbon dioxide levels—and then record a measurement for this stimulus.[1] The actual "sensing" components can be electronic, chemical, mechanical, fiber optic, or a combination. A thermometer is a common example of a sensor in its most basic form. However, a basic sensor can be equipped with memory, power, and the ability to wirelessly communicate with numerous other devices that can create a smart data collection environment to provide constant, real-time feedback. Sensors come in a variety of shapes, sizes, applications, and abilities. This section will delve into the different types of sensors and how they can be applied to different data collection applications.

The types of sensors and the range of their applications are constantly growing. This growth is being driven not by the researchers and manufacturers of sensor products, but by the consumers. If asked what kind of sensors they can produce, a sensor manufacturer's typical response would be "Tell us what you need it for and we can make it," albeit with the unspoken caveat that the consumer (or market demand potential) can provide enough money for the sensor's development. With that attitude, it seems that the possibilities for sensors are endless. The NCS program can not afford unlimited sensor development, but neither should it overlook existing or new sensors that don't immediately seem to fit the program's goals. In the following sections, several types of physiological monitors are described, including cardiac function. While pulse rate might not seem to be a routine variable to monitor during exposures to contaminants, particulate matter exposures at low concentrations have been observed to affect pulse rate variability. It may well happen that pulse rate variability is a general indicator for environmental contaminants.

This paper, then, will concentrate on the sensors that are already in existence, or at least in development. The main areas of application on which this paper focuses are medical/biological, environmental, and location.

2.1 Medical/Biological

Current medical sensor technology is moving away from stationary hospital monitoring devices and towards use in the field or at home. For example, ambulatory monitors are a type of portable sensor that is used outside of medical settings to detect physiological symptoms in an everyday, nonclinical environment. The most common devices monitor such physiological characteristics as blood pressure, glucose levels, physical activity, cardiac activity, and respiratory information.

Aerotel creates a number of at-home monitors that measure blood pressure, weight, glucose levels, and lung function.[2] The glucose monitor is small enough to be taken with a person almost anywhere and uses only the smallest needle stick, so it is considered pain-free by most patients. Glucose readings can then be transmitted to the doctor's office via telephone lines.

Future research will allow for wireless communication via cellular networks. Olympic Medical Center has created a portable cardiac heart monitor. When patients begin to feel chest pain, they attach the credit-card-sized monitor to their chests and the monitor records heart rhythm information.[3] With the use of wireless networks, this information can be transmitted directly to a hospital, in order to alert nurses and doctors in the case of emergencies. Ambulatory Monitoring, Inc. has created respiratory monitors that wrap around the rib cage and abdomen. These monitors are often used to measure breathing patterns while people are sleeping. Their monitors range in sizes that will fit newborn babies to the most obese subjects. In addition, Ambulatory Monitoring creates monitors to be used in animals, from kittens to horses.[4] Researchers at Johns Hopkins developed a portable—albeit relatively large (about the size of an 8.5" by 11" notebook)—monitoring device that can detect microbial viruses in the breath.[5]

Most of the devices mentioned above are portable, but they are not made to promote easy monitoring; carrying around a notebook-sized device or having to remember to hold a sensor to your chest every time you are having chest pain is not entirely convenient. New technological developments are creating wearable monitors that are designed to be so unobtrusive that individuals can be constantly monitored without causing much burden. Ambulatory Monitoring, Inc. has created a small wearable device used to measure body temperature. This device is 1.5 cm by 2.8 cm and can be attached directly to the skin via an adhesive strip. The device has a replaceable battery that lasts approximately 30 days. Though the device was designed to measure the temperature of infants who are most at risk for developing dangerous fevers, it can be used in adults, particularly the elderly.[4] Suntech Medical created a blood pressure monitor that people can wear under their clothing. This monitor unobtrusively takes blood pressure readings at pre-determined times throughout the day, a practice that is likely to yield more accurate results than readings taken in clinical settings often considered stressful by patients.[6]

Recently, portable cardiac monitors have become an important development in sensor technology. If an individual goes into cardiac arrest and he or she is not resuscitated within 6 minutes, the likelihood of brain damage increases significantly. For this reason, scientists at University of California, Berkeley and Precision Control Design, Inc. have developed a product called the Digital Doctor Wristwatch.[7] This device is worn like an ordinary wristwatch and used to monitor a wide variety of stimuli that could indicate cardiac arrest. The wristwatch includes an accelerometer and also measures heart rate information and pulse waveforms. Measuring pulse waveforms reveals information such as whether a person is in a state of shock, is about to go into cardiac arrest, or just needs to take a nap. Combined, these measures can tell if a person has fallen down and may be having a heart attack. If the warning light on the Digital Doctor begins to flash and an individual does not push a reset button indicating that he or she is alright, information can be sent immediately to call for an ambulance.[7]

Health sensors are also being developed to measure physical activity and sleep quality. Ambulatory Monitoring creates a device called a MotionLogger, which is used to measure sleep quality and quantity and other movement-related activities indicative of behaviors often seen in ADHD, geriatric inactivity, fatigue, surgical recovery, or neurological conditions. In addition, the MotionLogger will help identify disturbances in infant sleep patterns, which assists doctors in studying possible risks and causes of sudden infant death syndrome (SIDS).

IM Systems is responsible for developing a leg-activity monitor that is also used to monitor physical activity and sleep. This monitor is a light-weight, rugged device worn around the ankle using VELCRO straps.[8] This device can also be used to monitor sleep behavior patterns, exercise, and physical training.

Body Media created a wearable sensor that fits like a cuff around the upper arm. The Body Media device is designed for use in weight management, fitness, and wellness. The sensor measures total calories burned, duration of physical exercise, number of steps taken, energy expenditure, and sleep duration. This device can store up to 14 days worth of information and can wirelessly transmit data to a PC or PDA, so that a coach or trainer can be tuned in to a client's performance. Body media is currently working on developing a patch-style device that will be capable of monitoring the same types of physiological measures.[9]

The devices mentioned above are portable and mostly unobtrusive when worn individually. However, if someone had to wear a cardiac monitor, respiratory monitor, and motion activity sensor, all of these devices together may be somewhat burdensome. VivoMetrics has hoped to combat this problem by fine tuning a product called the LifeShirt, which combines multiple sensors into one light-weight, machine-washable garment, similar to the example in the introduction. The shirt is designed to monitor airway health in any type of environment by measuring heart rate and rhythm, respiratory patterns, and torso position (reclined or upright). The LifeShirt monitors body position and respiratory activity and provides objective observation on the state of asthma sufferers by recording information about the amount of time spent upright versus supine, the number of steps taken in a day, and restlessness during sleep. Future models will come with a removable digital memory card and can be powered up to 72 hours with 2 AA lithium batteries. Soon, the LifeShirt will be able to transmit data wirelessly and will contain environmental sensors as well as physical sensors.[10]

Another wearable device with multiple-sensor capabilities is the Smart Shirt from Sensatex. Designed for use in athletes, this shirt measures heart rate, respiratory rate, body temperature, and caloric burn. Both athletes and coaches can simultaneously monitor the athlete's performance by looking at readouts transmitted wirelessly from the Smart Shirt to a wristwatch or PDA, and this technology can be incorporated into any blend of fabrics.[11] The Smart Shirt currently has a battery life of up to 8 hours for continuous monitoring, or longer for intermittent monitoring.

The LifeGuard, a similar product developed by researchers at Stanford University and NASA, will soon become commercially available. This shirt was originally designed to physically monitor respiration rate, heart rate, activity, skin temperature, and blood pressure in astronauts.[12] However, Lifeguard also has applications for home-health monitoring, first responders, and military activities. Recordings can be wirelessly transmitted to a PDA or PC.

Intelligent Clothing creates a product called the SmartPatch, which is a non-invasive, credit-card-sized monitoring system weighing nine grams that can be embedded into clothing. SmartPatch is being used to measure cardiac and respiration rates, EKG, oxygen saturation, and temperature in infants. Radio technology is used to transmit these data to a bedside display unit that will trigger nurses or parents if a problem arises.[13] Future developments from Intelligent Clothing are moving toward fetal/maternal monitoring. These devices will be able to monitor neonatal respiratory fatigue by using chest wall shape recognition devices. These devices will also incorporate an alternative to ultrasound using 3-dimensional imaging of the heart and will allow for cardiac monitoring of both the mother and fetus.[13]

Similar devices are being created that can be embedded into any type of clothing. Philips Research Lab is creating a physiological monitoring sensor that can be embedded into women's bras. This sensor is also being tested in diapers and men's underwear.[14] Other companies are developing electronic textiles, which are fabrics that have physiologic sensors and electronics woven into them. Verhaert and Smartex are on the forefront on this development. Such garments will not only be capable of measuring and transmitting data, but receiving data as well.

Future research in medical/biological sensors is aimed at fine tuning smaller devices that contain multiple sensors in one unit, therefore making them less burdensome. Other developing research involves the use of implants. Implants have been used in animals to identify lost pets, but they are now being used in people as well. Recently Mexico's attorney general and about 160 other people in his office have been installed with microchip implants. These implants allow them access to secure areas of their headquarters. In addition, the implants serve as a kidnapping precaution in Mexico's turbulent political environment. Should any of the officials be kidnapped, the implants can be used to discover their location.[15]

Implant technology is now being considered for use in medical monitoring. Patients could be implanted with a micro sensor that would provide heart and blood pressure readings, among others. The doctor would simply run a handheld receiver over the patient's heart to read the sensor, rather than putting the patient through a costly CAT scan or other procedure. These devices have been tested in animals, and there are plans to run trials with humans as well.[16]

Microstrain creates a product called EmbedSense that was implanted into a patient's knee for a recent research study. EmbedSense monitors the knee for strain and other issues associated with the healing process after severe injuries or surgeries.[17] This small sensor is completely battery-less and relies on a wireless transceiver to read the information. The device is also used in engines and building structures to digitally monitor strain or fatigue. However, ethical issues and the invasiveness of such devices have limited implants from becoming widespread in medical monitoring.

Another medical technology that could be exploited with some development is typified by the home testing kits for pregnancy, ketones in urine, illicit drugs, and blood glucose. These tests represent applications of various measurement techniques that have a simple, direct readout (usually a color change). The tests are often based on monoclonal antibody assays and, therefore, could be used where such techniques are now possible. Monoclonal assays are, in general, very specific and usually quite sensitive.

Where tests already exist, it would benefit the NCS program to urge manufacturers to add RFID technologies to the readouts, so test results could be readily incorporated into the data stream. Where specific tests do not exist, the NCS program could consider seeding development of specific tests or guaranteeing long-term purchases to foster development.

While this list is not exhaustive, it is representative of some of the more pervasive sensors used in medical monitoring. The market for medical monitors is definitely growing, and thus new technologies are constantly being developed, making the sensors smaller and more sophisticated. Some sensors are or will be focused on babies and small children, while others are more suitable for preteens and adolescents. It seems likely that much development will take place during the conduct of the NCS program.

2.2 Environmental Sensors

In addition to medical sensors, there are a large number of environmental sensors available. The most common use of environmental sensors is to measure variables associated with water or air quality, such as temperature, humidity, air flow, light, smoke and particle concentration, and pollutants. Environmental sensors are also used as security devices for building alarms, to detect toxic gases, and to measure fatigue in buildings and structures.

Weather stations rely heavily on environmental sensors. The Oklahoma mesonet has multiple weather stations established in every county to automatically monitor indicators like temperature, humidity, barometric pressure, rainfall, wind speed and direction, incoming solar radiation, soil temperature, and soil moisture. These sensors were created to be rugged enough to survive outdoor life in the harsh Oklahoma climate and can wirelessly send data to a host computer. The only downfall for such sensors is that they require a large power supply that can not be supported by battery power for very long and must rely on power lines or other sources of energy.[18]

Environmental sensors are also used for habitat monitoring, which measure stimuli similar to weather stations but are designed to be smaller and work off a fixed power supply. Researchers at Berkeley have established wireless sensor networks to allow for non-intrusive monitoring of sensitive wildlife. On Great Duck Island in Maine, these researchers have installed sensors that measure temperature, barometric pressure, humidity, and mid-range infrared.[19] Berkeley researchers designed the sensors to be as small and as unobtrusive as possible, so that the sensors do not disrupt natural processes. In addition, these sensors were designed to be durable in all weather conditions. Sensors were coated with 10-micron parylene sealant, which protects exposed electrical components from water. In addition, the nodes were designed to run for at least 9 months on one pair of AA batteries.[20]

Berkeley researchers are also installing miniature weather stations (about the size of 35 mm film canisters) into redwood trees. These devices last for about 3 months on battery power and record light, temperature, and barometric pressure. However, even smaller, cheaper, and less-rugged sensors of the same type have been designed by companies such as Crossbow Technologies and Sensicast that can used be used in the home and office environment.[21, 22]

Environmental Systems, Inc. has developed a product called Moisture Point that monitors water quality. This product is used to identify harmful amounts of pesticides, fertilizers, and hazardous waste in the ground water. The Moisture Point sensor will be very useful for monitoring water supplies and crops growing near landfills or other possible contaminants. Similarly, Moisture Point will also be useful for atmospheric research. This product can be used to study the relationships between soil moisture, temperature, and precipitation. Another product Environmental Systems creates, called Gro-Point, measures the moisture content in the soil, which will assist farmers to obtain higher yields and improve crop quality. Each of these systems allows for additional sensors for temperature, humidity, and other indicators to be added. These monitors can be incorporated into wide area networks for remote monitoring of large areas of land.[23]

Biolab Commercial Water has developed a water quality monitor to be used in swimming pools. This monitor measures the level of chemicals such as chlorine that are needed to maintain the pH and sanitation levels of water at swimming pools, spas, and water parks. This monitor can detect the pH and amount of sanitization chemicals present in the water and wirelessly transmit a report to a remote monitoring site. Offsite managers can remotely direct the BioLab system in order to automatically deliver the correct range of water treatment products needed to properly sanitize the water.[24]

Air quality sensors can also be used in conjunction with security sensors to monitor the environment of fragile or valuable objects in transport and storage facilities. Produce and meats must often be kept at very specific conditions during transport to prevent spoiling. ControlGen creates a product called Cargo Management System for cargo trucks. Sensors are set up to measure temperature, humidity, intrusion detection, or any condition that is critical for delivering the cargo at peak quality. These monitors use radio frequencies to transmit data back to the driver or warehouse.[25]

Sensicast creates Environmental Monitoring System (EMS) that can be used to measure environmental conditions of fragile objects, such as valuable artwork and rare books. The EMS node is thin and inexpensive, allowing it to be placed in numerous locations. The node records air temperature and humidity, wirelessly transmitting the information back to a PC or PDA. In addition, Sensicast has also developed a monitor called the Object Alarm System (OAS), which is often used in art museums. This device uses motion-based algorithms and software to detect light, severe touches, or weight dispersal. The transceiver is virtually invisible and can be attached to walls or frames rather than to the painting or artwork itself. Once the device senses a touch, it can wirelessly send a message to an alarm system. The battery life for both types of sensors is approximately 3 years.[26]

Another use for environmental sensors is the detection of harmful pollutants, chemicals, and toxic gas. Transducer Technologies offer a device that can measure various pollutants found in the air. The device itself is no larger than a deck of cards and has been used in the field for over 10 years. It can be fitted with sensors that can detect and measure carbon monoxide (CO), hydrogen sulfide (H2S), nitrogen oxide (NO), nitrogen dioxide (NO2), ozone (O3), and sulfur dioxide (SO2) gases at ppb to percent levels in air. The detection ranges anywhere from 0 to100 parts per million (ppm) for NO2 to 0 to10000 ppm for CO.[27]

Measuring pollutants and biochemical hazards is also an area of research at the Smart Sensors and Integrated Microsystems (SSIM) labs at Wayne State. They are developing systems for the National Institutes of Health (NIH) that can perform remote measures of reagents in the environment using a wireless device.[28, 29] This wireless device has a switch that allows it to detect chemical and biological agents in gas, liquid, or vapor. Most notably, research has been done using this device to detect E. coli in food and water.[30]

At the forefront of toxic gas monitors is a company called RAE Systems. RAE Systems creates various products designed to measure a number of different chemicals and volatile compounds, such as arsine, alcohol, benzene, toluene, xylene, NO2, SO2, pyridine, methane, ethane, ethanol, formaldehyde, hexane, ozone, and others. While all of RAE Systems's sensors are made to be portable and use battery power, not all of them can transmit data wirelessly. Some must be downloaded directly to a PC. In addition, RAE Systems does not create one sensor that is capable of measuring all chemicals of interest at the same time. The sensor system they create that would be most beneficial to the NCS is called the AreaRAE. The device can support up to five sensors measuring the chemicals listed in ***Table 2-1***. The battery power for the device can monitor for up to 67 hours at 1 minute intervals, and it costs approximately $7,000. This device contains a radio frequency modem, which allows it to transmit readings to a base controller.[31]

Thermo Anderson has developed a light-weight, handheld aerosol monitor. This device can measure mass concentrations of dust, smoke, mist, or fumes in the air. The level of detection for PM ranges from 0.001 to 400 mg per cubic meter. To obtain detailed information about the specific components of the particulate matter, you must use a filter that, after use, is sent to a lab

Table 2-1. Sensors Available for the AreaRAE System by RAE Systems[32]

Gas Monitor	Range	Resolution
Oxygen	0-30%	0.1%
Combustibles	1-100% LEL	1% LEL
VOCs	0-200 ppm	0.1 ppm
	200-2000 ppm	1 ppm
Carbon Monoxide	0-500 ppm	1 ppm
Hydrogen Sulfide	0-100 ppm	1 ppm
Sulfur Dioxide	0-20 ppm	0.1 ppm
Nitric Oxide	0-250 ppm	1 ppm
Nitrogen Dioxide	0-20 ppm	0.1 ppm
Chlorine	0-10 ppm	0.1 ppm
Hydrogen Cyanide	0-100 ppm	1 ppm
Ammonia	0-50 ppm	1 ppm
Phosphine	0-5 ppm	0.1 ppm

for analysis. The device weighs a little more than a pound and has a battery life of up to 70 hours. Currently this device cannot wirelessly transmit readings, but information can be downloaded from the device's memory to a PC. The cost for this device is around $3,700.[33]

Casella USA creates a similar hand-held, PC-downloadable product called the Microdust Pro. This device is slightly more advanced and can measure TSP, PM10, and PM2.5 over the entire measurement range of 0 to 2500 mg per cubic meter. The battery power for continuous monitoring with readings every 2 seconds lasts approximately 8.75 hours, but battery power for readings every 10 minutes lasts up to 15 weeks. This device costs $3,950.[34]

SKC Inc has developed a wearable personal dust monitor. The device is made to be clipped to a belt loop and the sensor is mounted near the breathing zone for more accurate measurements. The device can measure respirable, thoracic, and inhalable dust. It has a measuring range of 0.01 to 200 mg per cubic meter, for particles from 0.1 to 100 μm. It weighs 2.5 pounds, has a battery power of up to 8 hours, and contains a PC-downloadable memory card.[35]

The SAFEGARD project, which is being sponsored by European Union, is currently working on developing sensors to monitor and quantify the levels of Organophosphorus

Pesticides in the air. The goal of this project is to detect individual pollutants, even at low levels, using real-time monitoring. Results from this research project have not been released yet, but they should be followed, as the results seem promising for applications to the NCS.[36]

Under contract for the U.S. Army, Foster-Miller has created a low-cost, light-weight, infrared Chemical Impact Threat Monitor. This two-pound hand-held device can quickly and accurately assess the presence of hazardous chemicals on surfaces and liquids.[37] Future goals for the government consist of deploying highly accurate yet low-cost sensor networks that will be able to detect chemical agents and their concentrations within 2 minutes. Sandia National Labs believes that this technology is still 3 to 5 years out. However, they do have a prototype that is due to be released in Fall 2004 that can detect such chemicals as nerve and blister agents, in addition to some industrial toxins.[38] Most of these devices are meant to be handheld or to be mounted to military vehicles. In addition most devices are intended for isolated events and special situations—unless hooked into a power supply, batteries typically only last for 24 hours. Most toxic gas monitors are used for military purposes. However, in the future, technology stemming from military research will be applied to create bio-smoke alarms, which can be used around the home or schools to detect in hazardous agents in the air.

Toxic gas monitors tend to measure concentrations above and below threshold values (TLV) for toxic effects. These monitors are intended for safety monitoring and sounding alarms. The criteria pollutants of interest to the NCS program might be expected to have health implications at much lower concentrations when the exposure is continuous. Accurate measurements at low concentrations (<1 ppm) tend to be more expensive, requiring different principles of measurement. It is not clear at present whether the sensors in the current toxic gas monitors will be adaptable to measurements at these lower concentrations. This area might be one in which the NCS program could profitably foster evaluation and development.

Particulate matter (PM) concentrations can be measured as integrated samples by collection onto filters or by counting and sizing the particles. Currently, the technology does not allow this process to be fully automated. However, filter collection could be performed in a home if self-contained packages holding a battery, pump, filter, and control electronics could be assembled and delivered. The study participant would take the package and run the sampler for 24 hours (or any other period), and then ship it to a central site for PM determination and refurbishment. The process is fairly labor intensive, but robotic weighing of filters at a central site could reduce the burden of weighing. There are many research labs that have the capability to create a set-up like this.

Filter collection does have the advantage that the PM sample is preserved and can be archived for future analyses. For example, optical absorption measurements on filters make possible an apportionment of the particulate matter between black carbon (BC), environmental tobacco smoke (ETS), and non-absorbing particles.[39] XRF (x-ray fluorescence, a nondestructive technique) or inductively-coupled plasma mass spectrometry (ICPMS, a destructive technique) can quantify many elements in the deposit, and bioassays (destructive) can quantify some allergens.

Particle counting and sizing is routinely performed by optical particle counters, but the measurement has certain deficiencies. Particles too small for optical detection are not counted; particle sizing is affected by the index of refraction of the particles (generally not well known); high concentrations will overload the instruments; and the instruments are complex and expensive. Other types of optical instruments (called nephelometers) are simpler to use. These instruments still require calibration with the aerosol of interest to give a good approximation to the mass concentration and some training to use.[40,41,42] Particulate matter monitoring in NCS would likely require routine trained operator support and possibly some development, if filter sampling is worthwhile. Neither of these approaches seems suitable for routine deployment in the NCS program at present.

Sandia National Labs are also working on a microsensor with remote collection capabilities that will be able to detect aromatic hydrocarbons (e.g., benzene, toluene, xylenes), chlorinated hydrocarbons (e.g., TCE, carbon tetrachloride), aliphatic hydrocarbons (e.g., hexane, octane), alcohols, and ketones.[43] The sensor will be able to operate in wet or dry subsurface environments, and it is being designed to be highly sensitive. Sandia believes that this technology is still 3 to 5 years away from being commercially available.

In situ, remote detection of heavy metals such as lead, mercury, and manganese has not quite arrived yet. Most lead-detection technology is limited to detecting leaded paints in homes and offices. Brandt Instruments create a portable hand-held device weighing only 3 pounds that can be used to detect levels of lead in paint. This device is made to interface directly with a hand-held computer such as a Hewlett Packard iPAQ to quickly and easily store and interpret data.[44] In addition, scientists at the University of Illinois at Urbana-Champaign have recently developed a biosensor that works in a similar fashion to litmus paper. In the presence of specific metallic ions, the specialized paper will turn from a blue color to a red color. While holding a piece of paper to a wall and noting a color change in order to detect the presence of lead is a very manual process, scientist Lu claims that "Our ultimate goal is to develop a microchip array with different color schemes for simultaneously detecting many different metal ions."[45]

Brandt Instruments also has a limited, albeit portable field unit for mercury detection available. It is a slightly bulky hand-held device for the detection and quantization of mercury vapor at levels as low as 1 mg per cubic meter. The device weighs 7 pounds, has a battery life of approximately 10 hours, is capable of datalogging, and will download into a spreadsheet. However, the device is geared more for use in contaminated areas near mercury spills, and its high cost (approximately $9,950) makes it impractical for home use.[46]

The Sensors Research and Development Corporation (SRDCorp) began research on a surface acoustic wave mercury vapor sensor. The goal was to develop an inexpensive (under $2,000), fast, reliable, portable, and sensitive (detecting <200ppb) sensor for detecting and monitoring vaporized mercury in real time. Phase I and II of the development process were finished before the Department of Energy cut the funding for the project in March 2002, preventing further research and testing in order to finalize the product.[47]

2.3 Location Sensors

Location sensors are mostly used by commercial agencies for tracking their goods and products during shipping and storage. Radio frequency identification (RFID) tags are the most common type of location sensor, due to their low cost and small size. RFID tags essentially serve as a barcode that can be read by radio frequency transmission. These tags can carry all sorts of information about the product, such as the serial number, model number, color, location, or any other relevant information. The RFID tags will identify themselves when they detect a signal from a compatible device, such as an RFID reader. RFID tags can be active, passive, or semi-active. The passive tags are cheaper ($0.05 to $0.50) and smaller, but do not contain their own power source and are powered by the RFID reader through an antenna. Because these tags do not rely on battery power, they can last indefinitely. Active tags have their own battery and can transmit a signal to an RDID reader antenna, but are significantly more expensive at around $20. It is projected that active tags will eventually cost about $5 by 2005, however. Semi-active tags are a compromise between passive and active tags and cost around $1. These tags contain a battery, but primarily rely on the RFID reader power for communication.[48]

RFID tags can be programmed for a number of different needs, depending on the function of the tag. They can be read-only, write-once, and read-write. These differences will have an effect on the size, cost, and power of the RFID tag. Tags that are read-only are passive and pre-programmed by the manufacturer, making them smaller and cheaper than other tags. Write-once tags are similar to read-only but can be programmed once by an end user. Read-write tags are more sophisticated and can support more advanced technological developments.

Some advantages of RFID tags include that multiple tags can be read simultaneously; that they can have all-weather capabilities, allowing them to be read through water, surrounding metal, or dirt; and that there is no line-of-sight requirement to read RFID tags. Disadvantages are that most tags only store up to a couple dozen bytes of information, and most only have a range of transmission up to 10 feet.[49] In the NCS program, this limitation could be advantageous, because it would allow direct localization of the participant. That is, the percentage of time (and actual times, if desirable) that the participant spends within the range of the reader can be automatically determined. Some simple refinements could be added to ascertain whether the participant is indoors or outdoors at home. For active children, this measurement would be of value in estimating exposures to indoor and outdoor contaminants.

Current uses for RFID technology typically include point-of-sale operations, product tracking, mobile computing, and maintaining inventory or the supply chain. Point-of-sale operations include electronic toll collection, fast payments systems (such as Mobil/Exxon Speedpass), and vending machines.[50] Product tracking is commonly used so that companies always know where products are. For example, Toyota uses RFID technology to track car frames as they move through different points in the assembly plant.[51] The Department of Defense (DoD) uses RFID to track rations as they move from the manufacturer to the field.[52]

RFID technology for mobile commuting has taken off in the area of health care. Many hospitals are now incorporating RFID to keep track of patients' medical and billing information.[53] For example, a standard medical ID bracelet can be embedded with an RFID tag that allows hospitals to track and identify patients or doctors throughout the hospital. This identification can be used to limit or grant them access to certain restricted areas in the hospital, as well. In addition, information regarding a patient's medical history, such as allergies and past surgeries, can also be stored. Doctors can use a hand-held PDA to read the tags to get their records and then update the information after seeing the patient. The RFID tag can also contain information about the patient's insurance and bank account, and allow for automated billing transactions during hospitalization. RFID tags can also be used to track expensive equipment or to keep track of lab and biological specimens by attaching an RFID-enabled label to the products.[54]

However, the future of RFID technology is likely to be led by supply-chain management, with such giants as Wal-Mart and the DoD leading the way. Both Wal-Mart and the DoD are requiring suppliers to place RFID tags on all their products. The RFID tag will essentially serve as a more knowledgeable barcode, allowing for more accuracy in tracking inventory. Wal-Mart hopes to have their main suppliers using RFID tags by January 2005. An RFID reader at the dock door can automatically read the RFID tags located on pallets in the cargo truck. Warehouse management software can automatically record what shipments went where and update their warehouse inventory.[55]

Some future uses for RFID include implanting chips in medical instruments, thereby preventing doctors from leaving an item in a patient after surgery. Other uses are creating personal badges that can be used to identify where employees are and whether they arrived to work on time, and to prevent people from entering prohibited areas.

Appendix A (Product Information) provides a list of the different type of sensors, what they do, how much they cost, and their battery life.

2.4 Future of Sensors

One of the main limitations of the current sensor technologies as it applies to the NCS is that the sensors, while portable, are generally designed to be operated by trained technicians making measurements outside of the laboratory and in the field—not for the lay person (study subject) to use at home. However, if a network of sensors is created and this network is able to communicate with a single platform, it is possible to overcome this obstacle by placing the responsibility of measurement on the communication platform itself and not on the study subject. Thus, by using a single communication platform, researchers can create a smart environment where measures are collected automatically, either with or without need for direct intervention by the study subject.

The current trend among manufacturers is moving in this direction. Manufacturers are incorporating multiple functions onto a single communication platform, with the cell phone seeming to be the platform of choice, due to the ubiquity of existing cellular networks and the large consumer demand. The multi-function capabilities of cell phones, for instance web-enabled browsers and digital camera phones with external communication protocols such as Bluetooth, make this an appealing platform for the NCS. However, the limited computing power makes the cell phone platform unfeasible in its current state. A viable alternative would be to use wireless-enabled hand-held computers (or Pocket PCs, such as the Hewlett Packard iPAQ, among others), due to the wider range and custom-programmable applications that can be run on these computers (although the wireless networks would need to be set up) for each participant.

Researchers at RTI are currently developing a platform that would be directly applicable to the NCS through an EPA STAR Grant.[56] The purpose of this grant is to create an integrated data collection platform using a wireless-enabled hand-held computer (Hewlett Packard iPAQ), specifically designed to accurately collect exposure factor data in longitudinal surveys with low participant burden for time/activity/location/exertion-level (TALE) data, dietary consumption data, and use of pesticide products, household cleaning products, and personal care products. With the right sensor network in place, it is possible that a participant within the NCS who sprays a pesticide in their kitchen will trigger a sensor that detects the pesticide exposure, queries the individual through an alert to their hand-held computer with a predetermined questionnaire, and monitors any physiologic response that the individual may have had to the exposure—all within a matter a seconds after detection of the exposure. The individual components of this example are available today. However, the difficulty lies in integrating these components into one device and enabling them to communicate seamlessly with each other. Undoubtedly, future advancements will make this process more transparent.

The future of sensors and RFID is moving in the direction of nanotechnology and micro-electro-mechanical systems (MEMS). While definitions for each of these terms vary with their application, they collectively refer to any technology that is performed on the nanometer (one-millionth of a meter) scale. Sensors using nanotechnology will be extremely small, as well as low in cost, and able to detect minute amounts of change. For example, a toxic gas sensor would be able to detect even the smallest traces of a toxic gas in an area. This functionality can serve as an early warning, permitting more time for evacuation or reaction to a potentially hazardous situation. In addition, power demands for this type of sensor are in nanowatts, which is a dramatically lower demand than those of typical electronics. Less power allows for a reduction in the size of batteries or a dramatic increase in battery life.[57] Crossbow Technology, Inc. and researchers at Berkeley are the leaders in developing small sensors using MEMS. Crossbow Technology's main product, MICA Mote, is a low-power, wireless device that supports various third party sensors[21] and is fully integrated with Berkeley's software management package, Tiny OS. Tiny OS is an operating system that allows for wireless programming of the sensors. The sensors can be programmed remotely, and the new program is wirelessly communicated to the sensor through the radio frequency technology. This capability will allow the end user to decide on the level and frequency of monitoring. The sensors can be programmed to report readings every 5 minutes for a period of 5 days or program the sensors to be in sleep mode, only transmitting information when something is detected instead of at regular intervals. In addition, sensors can be programmed to be continuously monitoring. Currently, most sensors can only be programmed directly—not by wireless capabilities.

How frequently a sensor records information and transmits data is directly related to battery life. If the MICA Mote ran continuously, its battery would last for about 30 days.

However, in sleep mode, the device has a battery life of 20 years. Most sensors are programmed with battery-saving applications, allowing them to be in sleep mode until it detects something, and only then transmitting data (rather than continuously transmitting). Other applications allow for data to be transmitted at fixed intervals, such as every 20 minutes or whenever queried, which also saves battery power.[21]

The reason that Crossbow's MICA Mote products are the direction of the future is because of their ability to support third-party sensors, meaning that these products can be combined with sensors from a variety of different vendors even if those sensors do not currently have wireless capabilities. Future developments in the MICA Mote are worth pursuing, because this kind of technology will allow multiple sensors to be combined into one device. For example, as mentioned previously, a toxic gas sensor that can support only five different chemical sensors, and a handheld aerosol monitor that does not currently have wireless capabilities. With the MICA Mote, this is not a problem, because the MICA Mote has the ability to integrate these third-party sensors in such a way that you can mix and match the sensors you want to include, dramatically enhancing analytic capabilities. Currently, the number of third-party sensor that can be attached is limited only by power consumption.

While it is apparent that nanotechnology and MEMS are leading the way for future trends in sensor technology, what exactly this future will entail is still somewhat unknown. Unfortunately, most manufacturers are reluctant to discuss the specific details of most of their future sensor development, in the hopes of gaining a competitive advantage. However, it is clear that the sensors of the future will be even smaller, use even less battery power, and possibly detect a combination of outcomes, moving toward a ubiquitous computing environment.

2.5 Promising Technologies for Potential Applications in the National Children's Study

Of the current biological sensors available, integrated wearable sensors seem to be the most promising in terms of remote data collection, especially for infants. The devices measure a wide array of physiological signs, and most of the garments tend to be relatively unobtrusive. In addition, a number of them have already been used in medical studies to measure sleep apnea and other behavior problems. The concerns remains, however, that, unless the sensors become easily removable and transferable between clothes, they will no longer be as practical as children become older and more picky about what kind of clothes they want to wear. On the other hand, by that point it may be necessary to monitor the children only at night or just once a week, thus not causing as much of a problem.

Another concern regarding wearable sensors is cost. Right now some of these products cost around $10,000 each. However, similar albeit more limited devices only cost about $400 each. While the high-end products may be too expensive now, the price could drop dramatically as new technology comes out and competitors begin to make similar products. In addition, prices could potentially drop by half simply by ordering in bulk quantities. While implants seem promising in terms of their diagnostic capabilities and low-maintenance once implanted, they are still too invasive and prompt numerous ethical concerns. Several other health sensors have not been approved by the FDA for all of their potential uses and applications. More research and testing on the sensors of interest will have to be performed before any large-scale data collection operations can begin.

Another concern regarding biological sensors is the impact the sensor itself could have on the respondent's behavior. For example, there are several sensors that are designed as tools for tracking health and obesity. By being made aware of one's cardiac activity and health, it might prompt someone to change his or her behavior by becoming more health conscious, which could have an impact on the study.

Common environmental sensors such as temperature, humidity, and barometric pressure are already quite small and inexpensive for home use (around $8) and are supported by a number of companies. Toxic gas and chemical agent sensors are still a little pricey and currently not ideal for home and school environments, due to size and limited battery power. However most toxic gas sensors are extremely reliable because they are designed for emergency situations regarding hazardous materials and areas with contamination spills. An important thing to keep in mind about sensors while reading this document is that, just because a particular sensor has not been mentioned, does not exist yet, or is not exactly ideal at the moment does not mean that it is not possible. No vendor is going to develop a product unless they believe there is a market for it. For example, RAE Systems has more than 20 chemical sensors that, combined, can detect hundreds of different chemicals. However, RAE Systems does not have a sensor that detects diazinon, a chemical commonly used in pesticides. The key to discovering the necessary sensors is to build off of existing technology in the direction of the NCS. RAE Systems may be able to add a few more chemicals to the list of agents their sensors can detect. You must tell vendors what is needed, and they will see about creating it. At present, no one product will address all of the needs of the NCS.

Table 2-2 provides details about various chemical classes of interest for the NCS. This table compares current laboratory detection methods to field detection sensors available—if any are applicable. Although the table is not intended to be exhaustive, it does indicate that a few sensors are available for routine monitoring of these chemicals of interest. Most of the chemical contaminants require sampling with subsequent analysis to obtain the sensitivity and accuracy that are required to obtain good exposure estimates. For this reason, it may be reasonable for the NCS planners to address methods for automated (or at least semi-automated) sampling that can be easily deployed by participants and analyzed at a central site.

The biggest limitation in the area of environmental sensors is the lack of portable devices that can measure metallic content (such as lead or mercury) in the environment in a way that will be beneficial to the NCS. Most devices for measuring lead content in homes only focus on detecting lead-based paints on walls. While there are portable mercury analyzers (such as Lumex RA-915), these devices are extremely expensive at about $10,000 to $20,000 each, even for the least expensive ones. In addition, these products are designed to be used in the field by scientists, not for home use.[58]

In order for toxic gas and chemical sensors to be useful to the NCS, these sensors are going to have to be tailored to a home environment the way a carbon monoxide monitor is used in homes. Various manufacturers, such as Ogawa & Co., Drager, and 3M make samplers that can detect VOCs[59-62] and other criteria pollutants.[63] However, many of these are not designed for home use and must be analyzed in a laboratory. Right now, most of these sensors are meant to be held in someone's hand or attached to military vehicles to survey expansive geographic areas. In addition, most equipment costs are in the thousands of dollars. The costs for such sensors are extremely high because they are designed to be very specific and sensitive. There is a direct correlation between sensor sensitivity and specificity to it's cost. Investigators should carefully consider what is needed from these sensors and what type of data these sensors will be able to collect before implementing them in the field.

Another factor to consider when looking for sensors is not to focus too much on whether or not a specific sensor has wireless capabilities. As mentioned previously, these sensors can be integrated into a platform like the MICA Mote, an advantage that is particularly useful for environmental sensors, which tend to be larger than biological sensors. Installing five sensors on one device instead of using five different sensors should be less bulky and ultimately require less energy. In addition, environmental sensors in homes or schools could be set up to use DC power, which solves the problem of limited battery supply (although participants may need to be compensated for the use of their electricity to support these devices).

Table 2-2. Chemical Classes of Interest for Childhood Exposure[59-63]

Chemical Contaminants	Example Chemicals or Chemical Groups	Current Methods of Measurement	Level of Detection	Field Detection Sensors Available?
CORE CONTAMINANTS				
Particulate matter	PM2.5, PM10	Filter Nephelometer Particle Counter	1 µg/m3 filter 1 µg/m3 neph.	No
Criteria pollutants	Ozone NO2 SO2	Absorption/Ion analysis Gas Analyzers	~ 1 ppm electrochemical 1 ppm passive 1 ppb active	Electrochemical sensors Ogawa passive badges[63] Integrated sample; lab analysis
Allergens	Dust mite Rodent, cockroach, Cat allergens Mold spores Pollen	ELISA after sample extraction Culture/counting of viable allergens	~ 1 ng/ml extract ~ 1 count for culture	No
Metals	Mercury Methyl mercury Lead Manganese	Atomic absorption ICPMS after extraction	~ 1 ng/ml extract	Colorimetric tests for lead
Organophosphorus pesticides	Chlorpyrifos Diazinon Malathion	PUF sampling with analysis by GC/FPD or GC/NPD	Analysis range: 50 to 500 ng/mL of PUF extract	No
Pyrethroid pesticides	Cis-, trans-permethrin Cypermethrin Cyfluthrin Allethrin Bifenthrin Deltamethrin Esfenvalerate Cyhalothrin	PUF sampling with analysis by HPLC/UV	LOD = 0.2 to 10 µg/mL of PUF extract	No
Phthalates	Di-2-ethylhexyl phthalate Di-isononyl phthalate Diethyl phthalate Dibutyl phthalate	Filter sampling with analysis by GC/FID or GC/MSD	LOD = 0.01 mg/sample	No

(continued)

Table 2-2. Chemical Classes of Interest for Childhood Exposure (continued)

Chemical Contaminants	Example Chemicals or Chemical Groups	Current Methods of Measurement	Level of Detection	Field Detection Sensors Available?
VOCs	Aromatic hydrocarbons (benzene, toluene, xylenes),	Cannister sampling with analysis by GC/MSD	LOD ≤ 0.02 ng (≤ 0.5 ppb) species dependent	Dräger Chip Measurement System (CMS); field analysis; instantaneous sample[60] 3M Organic Vapor Monitor (OVM) integrated sample; lab analysis[59]
	Aldehydes (formaldehyde, acetaldehyde)	Impinger sampling, DNPH derivitization, analysis by HPLC/UV	LOD = 1-2 ppb	3M Formaldehyde Monitor integrated sample; lab analysis[61]
	Aliphatic hydrocarbons (hexane)	Cannister sampling with analysis by GC/MSD or GC/FID	Low ppb	3M OVM integrated sample; lab analysis[62]
	Halogenated hydrocarbons	Cannister sampling with analysis by GC/MSD	LOD ≤ 0.02 ng (≤ 0.5 ppb) Species dependent	Dräger CMS
SECONDARY CONTAMINANTS [information only]				
PCBs		PUF sampling with analysis by GC/MSD		No
PCDFs		PUF sampling with analysis by HRGC/HRMS	MDL = 0.01 to 0.25 pg/m3	No
Dioxins	TCDD	PUF sampling with analysis by HRGC/HRMS	MDL = 0.01 to 0.25 pg/m3	No
EDCs				No
Endotoxins		ELISA after sample extraction	~ 1 ng/ml extract	No

RFID technology could be an extremely valuable tool for tracking and organizing respondents' files and information. Attaching an inexpensive passive RFID tag to any survey, equipment, device, or sample that is sent to respondents can improve the quality assurance process, because the tag can essentially serve as a barcode for that respondent. Similar to a doctor using a hand-held PDA to update a patient's chart, respondents could use a PDA or hand-held computer to document when they completed a survey or collected a sample, which will automatically update an active RFID tag with read/write capabilities on the sample.

With these suggestions in mind, the first step is to identify those sensor capabilities that currently meet the needs of the NCS and the sensor capabilities that still need to be developed. Of those that still need to be developed, the next step is to try to identify current technology that is similar, and then talk to vendors about branching out into the NCS's needs. During this process, size, cost, portability, battery life, and wireless capabilities should be secondary considerations. If the technology for the sensor itself exists, it is likely that the sensor can be modified to meet the specific requirements of the project. In addition, it may be necessary to look at a multi-company solution. Use one highly compatible product like the MICA Mote or the RTI Integrated Longitudinal Survey STAR grant as the platform, and then have the manufacturer work with other third-party companies to develop the necessary sensors.

Regardless of the type of sensors used, they will only be as good as the network surrounding them. The use of a thermometer in a cargo truck would be severely limited if the driver had to constantly stop the truck and open the back door to read the device. A network that allows one to collect information from as many sensors as necessary and communicate that information to remote sites is absolutely crucial. An organized network will also need devices to store this type of information.

3.0 NETWORK TECHNOLOGY

Network technology serves as a communication tool, connecting people and machines. The sensors are used to gather information about an individual or environment. Then, networks work to read, store, and communicate the information gathered from sensors. The end point for this information is usually a host computer, where data can be monitored, processed, analyzed, or archived by an end user. In addition, networks are used to communicate information from the end user back to the sensors, such as in the example with the swimming pool monitor. If the initial reading reported that the chemical levels were too low, a program installed on the host computer sends a message back to the swimming pool monitor telling it to dispense more chemicals.

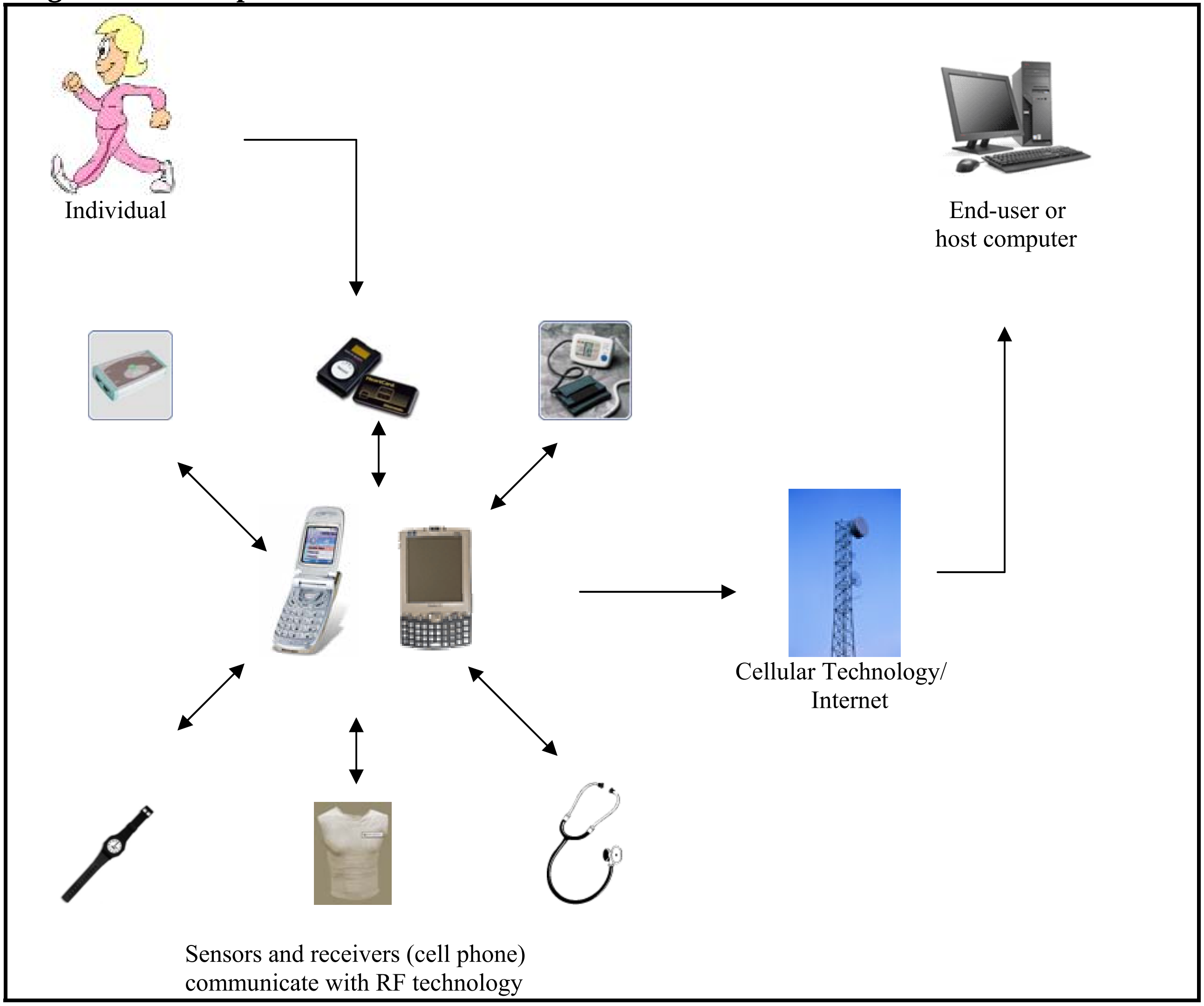
Figure 3-1 demonstrates how the different components of sensor networks all fit together. First, there is a person or environment that needs to be monitored. Next, there are various sensors that mechanically, chemically, electronically, or fiber optically detect stimulus in the physical environment. The data from the sensors are wirelessly transmitted using RF technology to a network infrastructure, such as a cell phone, PC, PDA, or transceiver. In addition, the PCs, PDAs, and other devices in the network can all be wirelessly connected to each other as well using RF technology. From this point, the information can be sent to remote locations using the Internet or cellular technology. Both the Internet and cellular technology work from an already established and growing infrastructure. The Internet relies on traditionally wired lines, and cellular technology utilizes base stations and towers to transmit data.

The focus of the rest of this paper will be primarily on the short-distance radio frequency communication, such as Wi-Fi and Bluetooth, and on the network structure, including range, communication, scalability, applications, and security.

3.1 Wireless Fidelity (Wi-Fi™)

The Wi-Fi™ Alliance is a nonprofit international association formed to create standards of interoperability for wireless networks. The goal of the Wi-Fi Alliance is to ensure that compatible products from different vendors will all be able to work together. The Wi-Fi standards are radio technologies called IEEE 802.11b, 802.11a, or 802.11g. This technology allows devices to connect to each other, the Internet, wired networks, or cellular lines. Wi-Fi is most often used in wireless personal area networks (WPAN) and in wireless local area networks (WLAN).[64]

Figure 3-1. Components of a Network



A WPAN is a network intended for individual usage, such as wirelessly connecting a PDA, desktop computer, and printer. Bluetooth and ZigBee, described below, are other examples of a WPAN. A WLAN, however, is structured more like a traditional wire-based LAN and is used to provide individual members of an organization or group shared access to a corporate network. The focus is on wireless connectivity within a specified area, such as an office building or campus. Wireless access points are necessary to define the region of coverage for the network.

A wireless wide area network (WWAN) uses cellular technology to extend a WPAN or WLAN beyond any given region. A WWAN can be created by using either a cable to a cellular telephone or through PC Card cellular modems. Sensor and Machine-to-Machine (M2M) networks can be used with both WLAN and WWAN. They are described in more detail in the following sections.

A Wi-Fi network consists of at least one computer equipped with a Wi-Fi adapter and a wireless access point or gateway, which manages communication between the wireless devices and the Internet connection. The wireless access point or gateway plugs into a broadband or modem connection (usually via Ethernet), allowing any device equipped with a Wi-Fi adapter to access both the Internet and other Wi-Fi-equipped computers and devices on the local network. In order to extend the wireless network, additional wireless access points will need to be installed. The use of 802.11g equipment is recommended, as it is the most current and has the fastest transmission speeds.[65]

Wi-Fi high-speed wireless Internet allows transmission of large files easily and quickly from anywhere in the network. According to International Data Corp, by 2005, 91 percent of laptops produced will have wireless capabilities installed. WLAN also supports voice communications, allowing people to make long distance phone calls inexpensively over the Internet.

WLAN is predominantly used to wirelessly connect people within businesses. Many commercial organizations, such as Starbucks or Panera, also create hotspots, allowing their customers to wirelessly connect to the system, while WPAN is primarily used in homes, allowing household members to roam about the home, and even slightly outside, while remaining connected.

The advantage of Wi-Fi is that it has the highest bandwidth of current wireless standards, which means that it can transmit more data. Wi-Fi can also support many devices (up to 128) within one network.[64] Linked networks can support even more. Wi-Fi can also transmit data up to 30 meters. In addition, the consumer can decide the level of security for their Wi-Fi network, create an open network or hotspot that allows anyone with a wireless adapter to connect to the network, or install security features that require passwords and encryption to prevent outsiders from accessing the network. However, WPAN and WLAN regions are finite and defined by access points that must be set up. Other disadvantages of Wi-Fi are that it needs more power and costs more money than other wireless radio technologies, such as Bluetooth.

3.2 Bluetooth

Bluetooth, similar to Wi-Fi, is a wireless technology that relies on radio frequencies to transmit data. However, instead of using the 802.11 standard, Bluetooth operates on the 802.15

standard. The difference between the two products is that Bluetooth tends to be utilized more for the lower-end, cheaper products, requiring lower power and less data to transmit. This difference does not necessarily mean that Wi-Fi is better. Bluetooth is relatively inexpensive and is ideal for monitors or sensors that require little power and low bandwidth. Bluetooth was developed to be small and inexpensive, with no line-of-sight requirements.[66]

Currently, the distance between the antennas for Wi-Fi devices versus Bluetooth devices will determine if they can coexist within the same device. If the antennas are placed right next to each other, this positioning will cause too much interference. However, there are groups working on establishing a Bluetooth and Wi-Fi coexistence in the future, and possibly combining the two products into a single product.[67]

Bluetooth technology has three classes of radio transmission. Class 1 has a maximum transmit power of 100 milliwatts. Class 2 has a maximum transmit power of 2.5 milliwatts. Class 3 has a maximum transmit power of 1 milliwatt. The transmission mode is used only when necessary and for the shortest amount of time possible. The gross data rate of Bluetooth is 1 Mbps.[67] The lower levels of transmission use less power and will allow the battery on the Bluetooth-enabled device to last longer.

The 802.15 frequency standard can be shared by any number of other devices, and, if too many other neighboring devices are in use, the speed of transmission can be severely limited. In addition, a microwave oven is an effective jammer for low-powered Bluetooth devices.[67]

Bluetooth also offers dial-up networking, which defines a link between a cell phone and a computer. Bluetooth can also be used with both a WPAN and WLAN, just as Wi-Fi can. Bluetooth can also wirelessly interface with cellular phones providing wireless WAN to corporate networks or the Internet. Bluetooth is the preferred wireless technology for WPAN, but Wi-Fi technology is preferred for WLAN.[67] This preference is because WPANs tend to be smaller with fewer devices, and do not offer as much data transfer.

Bluetooth applications best support personal computing applications. For instance, wirelessly transfer an image from a camera to a PC for storage and editing, and then send that image to a printer anywhere in the network to be printed. Other examples include the ability to transfer, edit, and delete files on one computer from another computer on the network; use a wireless headset to make phone calls from a mobile phone or PDA, or use a wireless headset to listen to a CD playing on a laptop without taking it out of its briefcase; synchronize the calendar on a PDA and desktop computer so that, when the user’s PDA is within the vicinity of the user’s desktop, the user's computer will automatically synchronize its calendar to that of the PDA and vice versa.[68]

Printers, PCs, PDAs, laptops, keyboards, fax machines, mobile phones, and most other digital or electronic devices can be integrated into the Bluetooth system. One can use a wireless connection to a mobile phone to cordlessly connect a PC to the Internet, no matter the location. One can send and receive e-mails from a cordless phone, no matter the location, even while the laptop is still in its briefcase. Monitoring devices using mobile phones can inform parents if their children have left a 30 foot radius. Bluetooth-enabled pulse oximeters can transmit pulse readings to a PC or other device.[68]

IBM has developed a Bluetooth-enabled wristband blood-pressure-monitoring device. This device can also check other vital signs, such as heart rate, by simply pressing a button on the watch. Blood pressure or other readings are gathered from the sensors using a Bluetooth short-range radio connection. Once transmitted, IBM's secure access and encryption ensure that only authorized medical personnel see the patient's data. If an unexpected reading is reported, either the patient can be sent a message reminding him or her to take medication, or the doctor could recommend a new prescription.[69]

IBM's Bluetooth-enabled devices are part of a larger mobile health system. The system utilizes currently available peripheral devices from a variety of manufacturers. These peripherals consist of glucose, blood pressure, heart rate, activity and ECG monitors, as well as peak flow, inhalation, injection, auscultation, and tablet dispensing devices. Of all these peripherals, only the activity and heart rate monitors are wearable. The others are all stand-alone devices. The system utilizes a Java- and Bluetooth-enabled cell phone to deliver data from the various peripherals into the centralized system. The mobile health system is being designed to support healthcare workers. That IBM is thinking of these types of applications bodes well for future tools and useful product offerings.[70]

Some advantages of Bluetooth are that the technology limits the power output to exactly what is required for the activity. For example, if radio signals indicate that incoming data are from a device that is only a few feet away, the Bluetooth device modifies the signal strength accordingly to suit the exact range. This capability allows Bluetooth devices to consume significantly less power than a device using a modem or other type of technology, thereby giving these Bluetooth batteries longer lifetimes.

There are no line-of-sight requirements for Bluetooth. Another advantage is that ABI Researchers predict that, by 2009, half of all cell phones may be able to read RFID tags. Implications for this technology are that it may become possible to make reservations for theatre tickets simply by holding a phone 20 centimeters away from a poster advertising the performance. Without actually dialing anyone or speaking with any person, someone could purchase concert tickets or book a hotel room. An RFID tag in the phone will contain credit card information, and the transactions would automatically withdraw money from one's account.[71] Or, in terms of the NCS, incentives could automatically be credited to a person's bank account after completing certain parts of the study.

One disadvantage of Bluetooth is that it only has a 10-meter range for most applications. This range can be extended to 100 meters by increasing the power supply by 400 to 1,000 percent. At the 100-meter range, many Bluetooth devices only supports one-way communication and data transfer between devices, whereas shorter communication ranges support two-way communication. One network can only support up to 8 devices; however 10 networks can be linked together, allowing up to 80 devices to be connected in a 10-meter bubble.[72]

Bluetooth comes with built-in encryption and authentication, which makes the technology very secure in any environment. The ability of Bluetooth to use only enough power as required makes it difficult to eavesdrop or intercept transmissions.[73] Bluetooth can support three levels of security: low, medium, and high. With low security, a device does not require any sort of security procedure, which means that any person can use the device in the network. Medium security allows all individuals access to certain functions on the device without authentication, but not to other functions. The high security level requires authentication and authorization in order to access any function on the device.

A new Bluetooth prototype named Enhanced Data Rate (EDR) will be launched by 2005. EDR will allow faster transmission speeds and use even less power.[64] Devices with the new EDR Bluetooth technology could transmit data up to 3 times faster.[74]

ZigBee is similar to Bluetooth, but its applications are more geared for static networks requiring many devices that are infrequently used and that need to transmit small data packages. Typically, ZigBee applications are cheaper but even more limited than Bluetooth in terms of the amount and frequency of data that can be transferred.[75] Refer to ***Table 3-1*** to compare and contrast the different radio frequency technologies.

Table 3-1. Comparison of Radio Frequency Technologies[49,76]

	Wi-Fi™	Bluetooth™	ZigBee™
Applications	Video, email, large files	Audio, small documents	Readings, monitoring
System Resources	1MB +	250KB +	4KB – 32KB
Power	20dBm	0 – 20dBm	0 – 7dBm
Nodes Per Network	128	8 – 80	255
Bandwidth (kbps)	11,000+	720	20 – 250
Standard	802.11b	802.15.1	802.15.4
Range(meters)	Up to 100	Up to 10	Up to 75
Key attributes	Reliable, low power, inexpensive	Low cost, convenience	Speed, flexibility

How can one decide which wirelessly technology is best? Most decisions will depend on the sensor itself. Sensor manufacturers typically recommend which type of radio frequency would be most economical for the situation at hand. In addition, Intersil, Mobilian, and Silicon Wave are creating chips that support both technologies. The chips can be added to cell phones or other devices and are then able to be used with whichever technology is most suitable.[68] However, when all other factors are equal, Bluetooth and Zigbee are currently the cheaper options. The most important factors influencing the decision will be range and the amount of data that needs to be transmitted. These two factors will have direct implications on the cost of the system. Deciding which type of radio frequency technology will be one of the last steps in setting up a sensor network.

At this point, it is impossible to say which wireless technology will be at the forefront in the future. For now, each technology has areas where it is most ideal. If Bluetooth prices drop significantly (from about $50 in many devices), ZigBee could become obsolete. In addition, new technology is always being developed, and a new product could come out at any point and out-perform all the existing technologies. The current buzz is about a new technology called Ultrawideband (UWB), which has been deemed Bluetooth on steroids. However, this technology is still at least 3 years away, and there is no guarantee that there will be a market for it when it does arrive.[77]

For any wireless technology to become successful, it has to have companies that support its existence. Therefore, the future of wireless technology is likely to be guided by the manufacturers and customers that use the various types of communications. Currently, Wi-Fi is more ubiquitous and has a longer track record than Bluetooth. However, Bluetooth has quickly gathered a large following. Only time will tell if there will be a dominant standard in wireless technology for all applications, or if consumers will have to choose which technology will be ideal for their given situations.

4.0 NETWORKS

Networks allow sensors to remotely communicate with each other and with other electronic devices, such as PCs and cell phones. Aside from using different radio frequencies, networks can vary greatly in size and structure, and this variance is primarily dependent on the type of environment that needs to be monitored. Bluetooth networks, for example, are generally the size of a 10-meter bubble. Wi-Fi networks can be expanded to the size of college campuses by installing more access points or towers used to transmit and receive radio frequencies. Without extended access points or towers, their range is approximately a 30- to 100-meter bubble, depending on the device. Additionally, if the networks are set up outside, they can potentially transmit up to 400 meters.[78] However, even these finite networks can still be connected to other devices thousands of miles away using the Internet or cellular lines.

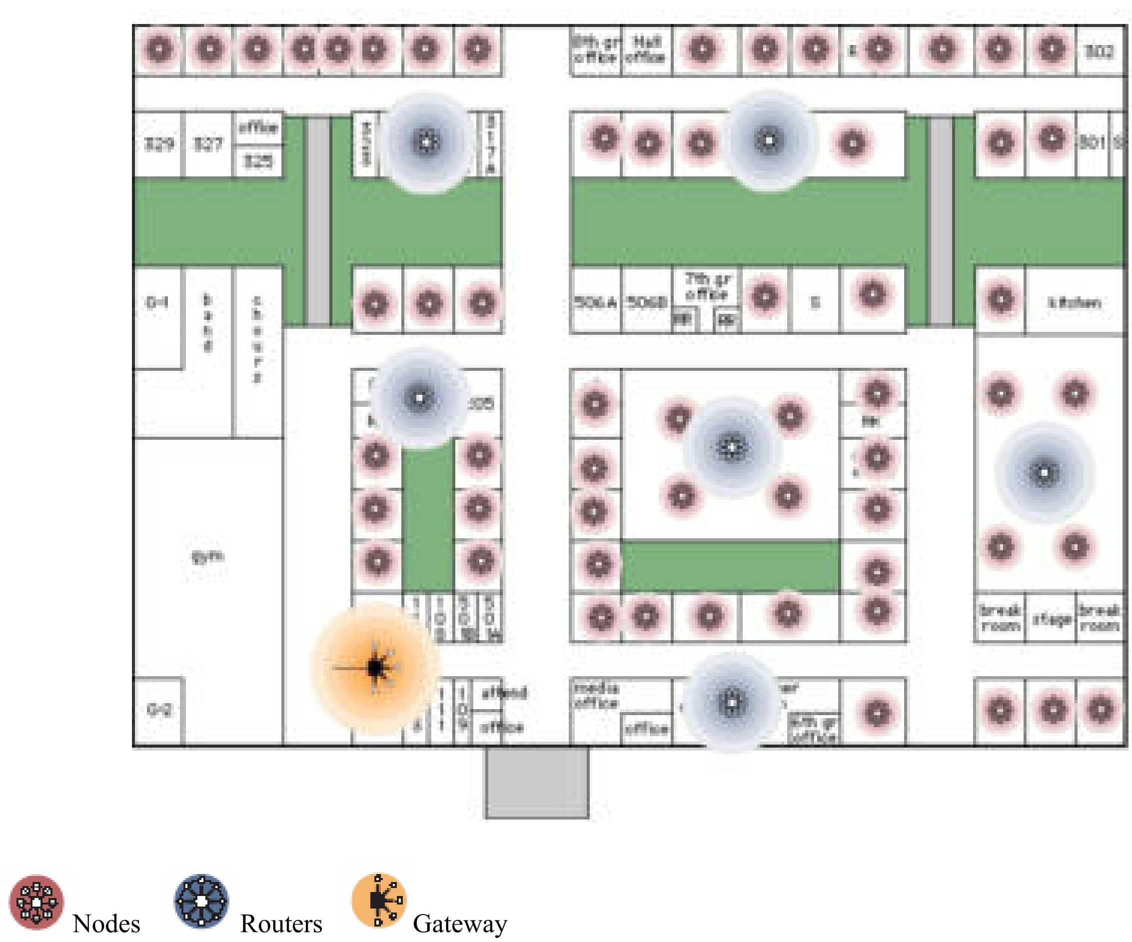
Networks consist of a variety of components that work together to wirelessly communicate information about the physical environment to a remote end user. A network generally starts with a host computer. This computer can be a PC, PDA, or other type of electronic device. The next component is a gateway or access point. The gateway can be connected to the host computer directly or wirelessly using RF technology. The gateway communicates with routers that can be strategically placed around the network area to maximize range. These devices typically include memory and support for DC power, which means that they can be plugged in to outlets, if the environment permits. The routers serve as a way to expand the network. The routers communicate with small battery-powered, wireless radio transceivers, called nodes. Sensors are usually directly attached to a node. Nodes contain a sensor interface that allows them to read the information collected by the sensor and transmit that information to the routers, and ultimately back the host computer. The nodes are usually smaller than routers and use less power. Most companies create nodes that support third-party sensors, which means that an assortment of sensors can be used with any one network. The last component is a type of software package that serves as a user interface, data manager, and network manager. This software's use is best integrated into the gateway or the host computer, rather than all the individual routers and nodes, in order to reduce the complexity of the nodes and save costs.

Gateways can be used to connect the sensor network with other traditional, wired networks, such as the Internet or cellular lines. Internet connections and mobile lines are very valuable, because they allow for the ability of remote monitoring and programming.

Many sensors contain an embedded computing platform that allows them to be programmed remotely, such as Crossbow's MICA Mote. An end user can reset the thresholds on chemical sensors or adjust how frequently sensors collect and transmit information. The final step is using the Internet and cellular lines to extend a network from a personal area network or local area network to a wide area network.

Because recent studies have shown that many schools in the United States have unsatisfactory air quality,[79] we include ***Figure 4-1***, which gives an example of how a Sensicast sensor network can be set up and used to monitor a school building.[80] A particular problem associated with poor air quality in schools is mold, which is a factor often associated with asthma in children.

Figure 4-1. Typical Sensicast Network System[80]



Source: Sensicast Systems, Inc.

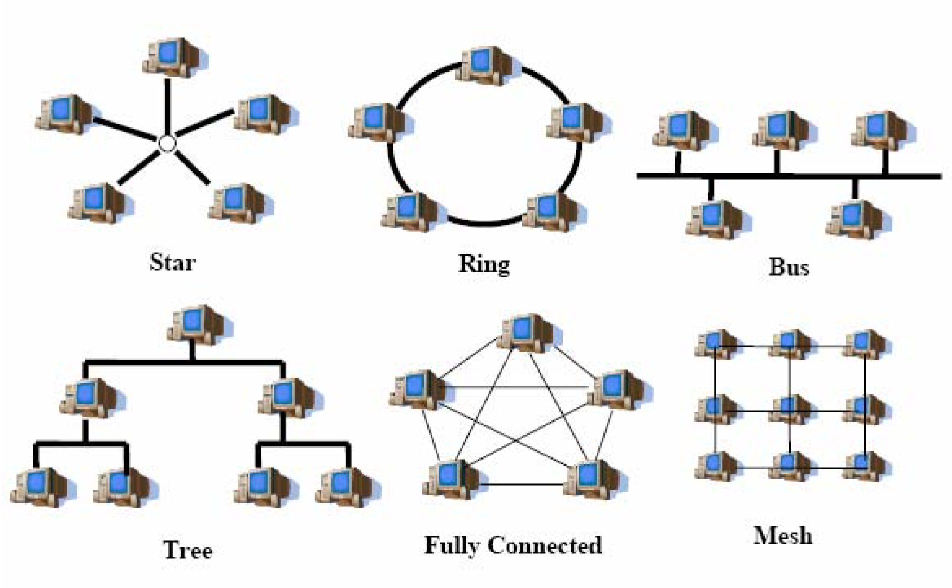
In this example, nodes can be placed in out-of-the-way shelves within classrooms of interest and fitted with various sensors measuring humidity (which leads to mold and fungi), carbon monoxide, carbon dioxide, volatile organic compounds (emitted from copy machines, adhesives, paints, cleaning chemicals, and cigarette smoke), biological contaminant (such as bacteria and viruses), ammonia, propane, and anything else of interest.[76] Routers can be set up in hallways near electrical outlets to extend the range of the network to cover all classrooms. Information collected from the sensors immediately flows through the networks and back to the host computer. The host computer can be connected through the Internet to a remote monitoring site that observes all of the schools in the state. A software package can be integrated to analyze the information collected and used to send out a report or sound an alarm if a network exceeds a suitable threshold for any condition.

This particular system takes less than a day for installation, and the installation could be performed by any PC-literate person in the school. The cost for installing a system in a 20-classroom school using the software package, one gateway, 3 routers, and 10 nodes monitoring temperature and humidity would cost less than $7,500. In addition, it is likely that this cost will drop over time.[22]

The above scenario is one example of a sensor network, however the ways in which nodes communicate can vary greatly, even in this one type of application. Zigbee or Bluetooth radio technology is used when the battery life of sensors and nodes needs to be extended and only small amounts of data need to be transmitted periodically, such as temperature every 20 minutes. Systems that are set up for temporary monitoring can be adapted to support DC power; systems that need to communicate large packets of information will typically use Wi-Fi technology, for example if video feed or other large data files need to be transmitted.

The way that nodes communicate also depends on the network structure, or how the nodes are configured to interact with each other. The simplest structure for communication is the star node. In this system, a central node is designated as the coordinator. Each node in the network can only communicate with the central node. This type of network is limited in scalability and reliability. ***Figure 4-2*** shows several different structures for network communication. The star, ring, and bus topology setup suffer from unreliability. In the star configuration, if the hub dies, the entire network is destroyed. In the ring configuration, if one link is severed, the entire network is down. The same applies to the bus topology. Fully connected networks are impractical for large networks, due to complexity arising from all nodes in the networks being connected to all other nodes. As nodes are added, the number of connections raises exponentially, creating routing problems. The most robust kind of network structure is the mesh network, which could be easily implemented in the schoolroom example above.[81]

Figure 4-2. Typical Network Structures[82]



In a mesh network, nodes typically communicate with the nearest neighbors, allowing the network to remain flexible. A benefit of mesh networks is that they are self-configuring. As soon as a node is powered on and is within range, it will automatically configure the entire network. In addition, mesh networks are self-healing. As nodes are added or removed, the remaining nodes can automatically reroute their transmission to ensure the most reliable, efficient type of communication.[22] Therefore, for example, adding or removing monitors from different rooms in the school would not affect the network. Mesh networks also support what is called "multi-hop routing." Data from one node can literally hop through other nodes to deliver information to a gateway, avoiding interference with other nodes that are already communicating. Mesh networks also support bi-directional data transmission. Not only does this form of transmission allow for the acknowledgement of every radio transmission, but it allows commands from the host computer to be sent out to the individual nodes. Therefore, if researchers knew a day was particularly hot in one part of the county, they could program the sensors to report information every 5 minutes instead of every 20 minutes. All of these factors help to extend the scalable range of the network such that it can, in theory, support an unlimited number of nodes. Current mesh networks have been able to support hundreds of nodes reliably and quickly. Crossbow Technology is working on a network deployment that will support up to 10,000 nodes.[21]

In a well-connected system, nodes can enter and leave the network without interfering with communication, which is ideal for any kind of network that might be constantly changing by adding new monitors or removing ones. This capability also allows for networks to move as long as the sensor nodes are still within range of the bridge node that connects them with the Internet or cellular lines. The cellular systems used rely on public networks usually operated by wireless carriers, such as Verizon, T-Mobile, and Cingular. The four main wireless access technologies to choose from are GSM, CDMA, iDEN, and analog. GSM is the recommended type of wireless module in practice. Monitoring devices can also network though Short Message Service (SMS).[83] Aeris.net provides M2M technologies that can access multiple cellular lines and integrate them into one network that provides the same functionality anywhere in the United States.[25] Sensor technologies can support multiple wide-area connection utilities, such as power lines, telephones, and broadband, all in the same area.

Ad-hoc networks are also possible with a mesh network type of structure. Ad-hoc sensor networks are a collection of sensor nodes forming a temporary network without any type of stationary infrastructure. This capability allows the network to be flexible and remain constantly moving, which is possible in mesh networks because there is no head or coordinator node. All nodes share the same responsibilities. Therefore, this type of network is often referred to as peer-to-peer networking. Mobile, self-configuring networks are often necessary for military types of applications, where it is often not predictable where a network will need to be set up or for how long.[78,81]

While mesh networks are the most robust type of configuration, there is more than one way that a mesh network can be set up. However, most vendors are capable of installing the most ideal setup for the situation. The factors that influence network structure are as follows: ease of deployment, network range, self-identification, system lifetime, time awareness for coordination with other nodes, standard control protocols, software capabilities, quality, and cost.

Sensor networks are sometimes referred to as Machine-to-Machine or M2M. The term is used for networks that are primarily driven by devices interacting with people and other devices, rather than people needing to interact with other people. For example, hotspots and businesses typically require networks that can support multiple computers and PDAs. These networks may need to transmit large files or videos constantly. However, in the school example, the sensors require much lower bandwidth and energy than most PC users.[74] With M2M, consumers are more interested in the services—such as remote access, ongoing monitoring, and self-healing capabilities—of a device, whereas networks connecting people to people rely more on the specific components of devices, such as processor speed, memory, etc.

Security of sensor network data transmission is of extreme importance. Someone with a powerful enough receiver and appropriately designed antenna could easily intercept the data stream. Therefore, the information sent must be encrypted, but the best means for doing so are still in debate. Other possible security-breach scenarios are more geared toward military applications, such as if a sensor node was "captured" or taken. Then, the information stored on it could be interpreted by someone else. In addition, an enemy could add a false node to the network that could interfere with the system. Current security efforts are geared toward ensuring authentication, integrity, privacy (or confidentiality), and the inability for messages to be played back. These measures will need to be tested in more detail. However, military solutions are at the forefront of testing these security devices, as these devices are most critical for their needs.[81]

Current applications of sensor networks are being used in medical, security, and intrusion detection, environmental safety, and homeland security emergency response networks. Harvard University and Boston University are currently developing a medical sensor network to be used for emergency medical care. The network, called CodeBlue, integrates low-power, wireless vital-sign sensors (such as heart rate and pulse oximeters) with PCs and PDAs to be used in medical emergency situations. CodeBlue is designed to be used in various types of network situations, from small clinics, to hospitals, to mass casualty sites. The devices in the CodeBlue system are capable of storing information on the patient's identity, status, history, and procedures, thereby eliminating cumbersome paper charts. The devices are also small, portable, completely wireless, and will operate on one pair of batteries for months.[83]

The use of sensor networks becomes most beneficial in remote areas, where manual observation would be extremely tedious if not impossible. For example, scientists at the University of South Hampton are using wireless sensors to monitor glacier dynamics and subsequent climatic change. The sensors are buried 60 meters into the surface of the glacier and are able record information about temperature, pressure, and movement within the glacier and of the sediments at its base. The information from various sensors scattered inside the glacier is wirelessly transmitted to a base station located on top of the glacier using radio frequencies. The information then travels over cellular lines from the base station to a server at the university, for continual monitoring of glacial behavior.[84]

Sensor networks have also been deployed in environmental observation and forecasting systems (EOFS). An EOFS is used to monitor the status of the Columbia River. This system uses 13 stationary sensors on the side of the river and one mobile sensor station located on a buoy floating in the river. The stationary nodes are powered by a power grid, but the mobile station gains power through solar energy. Each station contains sensors that monitor water depth, temperature, flow velocity, and other parameters. Each station wirelessly transmits data to a master station (located on shore) through radio frequencies. The master station is then connected to a host system over the Internet. The data are then fed into a physical environment model that is used to guide vessel transportation and forecasting.[85]

Sensor networks have been used by the military as well. Sensor nodes can be dropped from airplanes into remote areas and automatically create their own network. Dropping a robust, self-configuring, self-organizing wireless sensor network into a battlefield to obtain information presents an invaluable, strategic advantage. Collecting information about potential enemy movements, hazardous chemicals present, infrastructure stability, and climate and weather conditions are just a few of the military applications.[86]

One example of an M2M application is retailer Brookstone's Orb, which focuses on developing a unique, ambient device that also provides real-time information. For example, their primary product is a crystal-ball-shaped desk ornament that can change color to communicate any type of information, from the weekend weather, to the Nasdaq Index, to a patient's health status.[87]

An Italian electricity company called Echelon uses M2M technology to install and monitor electricity meters. These smart meters communicate by digitally monitoring electricity and transmitting household usage.[88]

Using a video camera and various monitors and sensors installed in a room, a Japanese company called emWare allows nursing home attendants to monitor patients more effectively. Monitors will generate alarms, such as "left the bed" or "agitated sleep," to signal attendants.[89]

Opto 22 has developed a wireless M2M system to be used in tracking the performance of heavy equipment and machines that are often very expensive and hard to access. The monitors record a machine's status, fuel level, oil pressure, temperature, etc., and report the information back to the headquarters.[90]

SmartSignal has been working with Delta to develop methods of tracking the health status of aircraft engines. Engineers can now monitor the life of an engine and signal analysts through e-mail, pager, or text messages when there is a problem.[91]

The main advantages of M2M are that communication between devices is bi-directional and it has single access points. In addition, M2M is easily integrated into existing cellular technologies.[25] Similar to other networking structures, all device communication can be encrypted automatically before being sent over the Internet.

5.0 CONCLUSION

As time progresses, sensors will become smaller and more elaborate in their measurement capabilities. Much of this technology is extremely new and, as these sensors become more wide-stream and used in practice, their prices will continue to drop—similar to how cell phones dropped in price after a few years. However, because much of this technology is so new, many devices have not been validated or tested. As mentioned earlier, several health sensors have not been approved by the FDA for some of the particular uses the NCS may have for them. This report is only a summary of products that are currently for sale or being discussed in the literature. No physical tests with any sensors were done to assess the quality or feasibility of the devices. The next steps should be to test some of the current technologies in the field and determine how valid and reliable the information collected from the sensors actually are compared to traditional collection methods.

Other issues arise in compatibility. As new radio frequency technology develops in the future, it will have to be backwards-compatible with most sensors and devices in order to glean all the benefits from a newer, faster means of communication. Another concern is that the technology is advancing so rapidly that certain sensors could quickly become outdated or obsolete. Fortunately, the most current sensor networks are already highly flexible, allowing sensors to come and go without interrupting the network. A highly adaptable network will be crucial in developing a data collection environment that will grow with technology over the course of the study.

Increased volumes of data would also be a concern, as the sensors will result in an explosive increase in data flows when networks become more ubiquitous. This increase will in turn raise a series of issues about how to deal with all the data. New data and storage management methods and techniques will be needed, and then new data mining tools will need to be developed in order to effectively extract relevant information from the data. Similarly, for sensor networks to be created, organizations will require new programming and implementation techniques specific to sensor technology. New security techniques will need to be developed to protect the information collected. Fortunately, many sensors with wireless capabilities already come with encryption techniques and data management software. However, the problem arises in integrating several different software packages into one centralized database and user interface. Using integrated data collection platforms such as Crossbow's MICA Mote,[21] IBM's Mobile Health Toolkit,[70] and RTI's Integrated Longitudinal Survey STAR grant[56] may simplify this process as these platforms are designed to be compatible with multiple sensors and able to communicate on various networks.

As health and environmental sensors become smaller and more geared toward home and community use, the thought of establishing a wireless sensor network for remote data collection is no longer hypothetical. Currently, a variety of health sensors can remotely monitor cardiac information, respiratory data, blood pressure, temperature, and several other important vital signs. In addition, environmental sensors can monitor temperature, humidity, pollutants, and other factors in a home or school environment. However, not all of these sensors are set up to operate within a wireless/ubiquitous environment at the present time. It would take some effort to get the various components coordinated. Thus, while it is technically possible to measure certain health and environmental endpoints using wireless networks, there will need to be careful consideration of the data capture and networking aspects before it can be fully implemented into the NCS. An off-the-shelf ubiquitous computing environment that will satisfy all the needs of the NCS does not exist at this time. However, with some time and effort, a combination of the technologies currently available could be adapted to the NCS. Future developments, such as the development of an integrated data collection platform using a hand-held computer and advancements in sensor technology, will make the ubiquitous computing environment envisioned closer to a reality and offer researchers from the NCS a wealth of new information at reduced burden on the study participants.

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APPENDIX A:
PRODUCT INFORMATION

Products	Company	Description	Commercially Available? How much	Invasive?	Battery Life	Where Can I Find More Information	Reference Number
Glucose Monitors	Aerotel	The glucose monitor is small enough to be taken with a person everywhere. It uses only a drop of blood and is relatively uninvasive. Glucose readings can then be transmitted to the doctor's office via telephone lines.	NA	No	NA	http://aerotel.com/products/ShowDetails.asp?iProductsID=29.	2
Instromedix King-of-Hearts; Instromedix Heart Card	Instromedix	Portable monitors that record heart rhythms over a fixed interval of time	Yes. $650 - $950	No	2000 minutes	http://www.instromedix.com/cardiac_event_recorders.htm	3
MotionLogger	Ambulatory Monitoring	Measure sleep quality and quantity and other movement-related activities, indicative of behaviors often seen in ADHD, geriatric inactivity, fatigue, surgical recovery, or neurological conditions	Yes. $2195 - $3500	No	60 Days	http://www.ambulatory-monitoring.com/catalog_AMI.pdf	4
Indotrace System Respiratory Monitor	Ambulatory Monitoring	Wearable respiratory monitors used to measure breathing patterns during sleep	Yes. $3300	Yes	1 9-volt battery	http://www.ambulatory-monitoring.com/catalog_AMI.pdf	4
Puck temperature monitor	Ambulatory Monitoring	Button-sized wearable monitor that measures body temperature. It adheres directly to the skin	Yes. $750 - $950	No	1 - 6 months	http://www.ambulatory-monitoring.com/catalog_AMI.pdf	4
SunTech Blood Pressure Monitor	Suntech Med	Portable Blood Pressure Monitor	Yes. $2690 - $3300	No	48-72 hours	http://www.suntechmed.com/	6

Products	Company	Description	Commercially Available? How much	Invasive?	Battery Life	Where Can I Find More Information	Reference Number
Digital Doctor on your wrist	AmphenolPCD	The wristwatch includes an accelerometer and also measures heart rate information and pulse waveforms. Measuring pulse waveforms reveals information such as whether a person just ate a hamburger cooked in old fat, if a person is in a state of shock, about to go into cardiac arrest, or just needs to take a nap.	No, proprietary	No	NA	http://www.amphenolpcd.com/index_win.htm	7
Leg Activity Monitor	IMSystems	This device can also be used to monitor sleep quality and behavior patterns. Other uses involve exercise and physical training monitoring.	Yes. $1398	No	2 weeks	http://www.imsystems.net/PAM-RL.html	8
Healthwear System by BodyMedia	BodyMedia	The Body Media device is designed for use in weight management, fitness and wellness. It measures total calories burned, duration of physical exercise, number of step taken, energy expenditure, and sleep duration.	Yes. $399	No	2 AAA batteries	http://www.healthwear.com/hw/product.do?task=display	9
Life Shirt by Vivo Metric	VivoMetrics	This light-weight, machine washable garment is designed to monitor airway health in any type of environment by measuring heart rate and rhythm, respiratory patterns, and torso position (reclined or upright).	Yes. $10000	No	Up to 24 hours	http://www.vivometrics.com/site/pdfs/find.php?file=VivoBrochureAsthma	10
SmartPatch	IntelligentClothing	Small, lightweight wearable device for infants that measures heart rate and respiratory information	Propreitary	No		http://www.intelligentclothing.com/index.html	13
Embed Sense	MicroStrain	Implantable device used to measure digital strain, temperature and unique IDs	Yes. $300 - $3000	Yes	indefinite	http://www.microstrain.com/wireless_sensors.htm	17

Products	Company	Description	Commercially Available? How much	Invasive?	Battery Life	Where Can I Find More Information	Reference Number
MICA Mote	Crossbow	MEMS device that supports other sensors such as temperature, humidity, etc.	Yes. $150 for the mote. Sensors extra		1-2 years	www.xbow.com	21
Moisture Point	Environmental Sensors Inc. (ESI)	Moisture·Point® is the only in-situ profiling moisture monitoring system consistently being chosen by regulators and environmental consulting firms in the USA, for use in site remediation and monitoring of landfills.	Yes. Complete system with 5-7 sensors for $8000			http://www.esica.com/profile/index.html	23
Gro-Point	Environmental Sensors Inc. (ESI)	Gro·Point™ meets the market demand for shallow, low-cost, non-profiling applications in soil moisture measurement, especially in irrigation control. Gro·Point™ is being marketed to agricultural consulting firms, distributors and dealers with early results indicating high product acceptance. Vineyards, citrus and other high value crops are already being monitored with Gro·Point™ in the USA	Yes. $100 for each sensor			http://www.esica.com/profile/index.html	23
Environmental Monitoring System	Sensicast	These sensors monitor environmental conditions of fragile objects such as valuable artwork and rare books. The sensors are small, and can record air temperature and humidity.	Yes. $7500	N/A	2-3 years	http://www.sensicast.com/art/buy_starter.php	26
Object Alarm System	Sensicast	This device uses motion-based algorithms and software to detect light and severe touches or removal of artwork.	Yes. Full System, $4999	N/A	2-3 years	http://www.sensicast.com/art/buy_starter.php	26

Products	Company	Description	Commercially Available? How much	Invasive?	Battery Life	Where Can I Find More Information	Reference Number
Toxic Gas monitors	Transducer Technology, Inc	Portable, lightweight sensors that detect various toxic gases in the air	Yes. $35 and up.	No	2 years	http://www.transducertech.com/products/index.html	27
Hazardous Chemicals Monitors	SSIM at Wayne State	Detect volatile organic chemicals and other hazardous material in the air.	No	No		http://www.ssim.eng.wayne.edu	29
Toxic gas and radiation sensor	RAE Systems	Light portable device designed for detecting hazardous chemicals and volatile organic compounds	Yes. AreaRAE wireless - $4500 - $7000	No	14-24 hours	http://www.raesystems.com/product/category/detail/62	31
Wearable physiological monitors	Foster-Miller	Foster-Miller brings practical, rugged, comfortable textile expertise to the incorporation of sensors in wearable garments. This system provides tracking and evaluation of an individual's physiological condition, such as hydration level, alertness, and heart rate, based on a platform of gel-free sensors	No	No		http://www.foster-miller.com/projectexamples/t_bt_physiological_monitoring/Wear_Forget_Sensors%20.htm	37
Hazardous chemical monitor	Foster-Miller	A hand held device that could rapidly assess the presence of hazardous chemicals whether in airborne vapor or liquid phase on surfaces	No			http://www.foster-miller.com/projectexamples/t_sensors/hand_held_chemical_threat_sensor.htm	37
Vital Dust	CodeBlue - Harvard	These devices collect heart rate (HR), oxygen saturation (SpO2), and EKG data	No	No	6 days	http://www.eecs.harvard.edu/~mdw/proj/vitaldust/	83
Cargo Management System	ControlGen	Sensors are set up to measure temperature, humidity, intrusion detection, or any condition that is critical for delivering the cargo at peak quality.	Yes. Individual sensors: $8 - $150; Gateway: $500 - $1000;		12 months	www.controlgen.com	
RFID passive tags		Used in labels to replace barcodes	Yes. $0.05 - $0.50		Indefinitely		

Products	Company	Description	Commercially Available? How much	Invasive?	Battery Life	Where Can I Find More Information	Reference Number
RFID semi-active tags		Barcode labels used for tracking high-value goods	Yes. $1		10 + years		
RFID active tags		Barcode labels used for tracking high-value goods	Yes. $20		5-10 years		

APPENDIX B:
RESOURCES

Device Type	Company	Description of Products, Services or Information Provided	Contact Information	Reference #
Sensor	Accenture	Accenture is a global management consulting, technology services and outsourcing company. Committed to delivering innovation, Accenture collaborates with its clients to help them become high-performance businesses and governments. They provide services related to implementing sensors and sensor networks in a wide array of applications.	URL: http://www.accenture.com/xd/xd.asp?it=enweb&xd=services\technology\vision\sil_sensors.xml Email: n/a Phone: n/a	1
Sensor	Aerotel	Aerotel has developed a telemonitoring system that can send results from a home glucose test to a centralized location for review.	URL: http://aerotel.com/Products/ShowDetails.asp?iProductsID=29 Email:usa@aerotel.com Phone: 888-921-2900	2
Sensor	Instromedix	Instromedix specializes in portable cardiac monitors capable of capturing episodes of Atrial Fibrillation (AF), tachycardia and bradycardia. The unique benefits provided by the device may include early diagnosis and intervention, improved patient care and follow-up, and an increased ability to document breakthrough episodes.	URL: http://www.instromedix.com/ Email: n/a Phone: 800-633-3361	3
Sensor	Ambulatory Monitoring, Inc. (AMI)	Ambulatory Monitoring specializes in developing tools for measuring activity levels, light, sound, temperature and respiration. Many of their devices fit in a wristwatch styled platform, while their respiratory system utilizes bands that can easily be wrapped around the rib cage to detect respiration volume.	URL: http://www.ambulatory-monitoring.com/index.html Email: info@ambulatory-monitoring.com Phone: 914-693-6604	4
Sensor	Suntech Medical	SunTech produces motion tolerant blood pressure sensors.	URL: http://www.suntechmed.com/ Email: sales@suntechmed.com Phone: 919-654-2300	6
Sensor	AmphenolPCD	AmphenolPCD is a private sector company that collaborated with Berkeley University on the Digital Doctor wristwatch ambulatory monitoring device. The device is designed to not only notify emergency personnel in the event of a fall or accident, but also track vital signs in order to detect health maladies in the wearer.	URL: http://www.amphenolpcd.com/index_win.htm Email: info@amphenolpcd.com Phone: 978-532-8800	7
Sensor	IMSystems	IMSystems produces a motionlogger that can be attached to the ankle and record activities. The device can determine whether the leg is upright or supine and marks the data accordingly.	URL: http://www.imsystems.net/PAM-RL.html Email: mail@imsystems.net Phone: (410) 296-7723	8

Device Type	Company	Description of Products, Services or Information Provided	Contact Information	Reference #
Sensor	BodyMedia	BodyMedia manufactures a device that can be worn on the upper arm to provide physiological data, including: caloric expenditure and intake; sleep information; and vital signs. The device can be plugged into a PC so that the data collected can be downloaded and integrated into a data collection system.	URL: http://www.bodymedia.com/index.jsp Email: info@bodymedia.com Phone: 412-288-9901	9
Sensor	VivoMetrics	The LifeShirt System is the first non-invasive, continuous ambulatory monitoring system that can collect data on pulmonary, cardiac, and other physiologic data, and correlate them over time.	URL: http://www.vivometrics.com Email:info@vivometrics.com Phone: 805-667-2225	10
Sensor	Sensatex	SmartShirt developers Sensatex have incorporated smart materials technology into a garment that can be worn and washed like any clothing. Unlike normal clothes however the SmartShirt is capable of gathering physiological information while worn.	URL: http://www.sensatex.com/index.html Email: info@sensatex.com Phone: (240) 644-0242	11
Sensor	Lifeguard	Lifeguard is comprised of physiological sensors (ECG/Respiration electrode patch, Pulse Oximeter, Blood Pressure Monitor), a wearable device (CPOD), and a base station (Tablet PC). The wearable device acquires and logs the physiological parameters measured by the sensors. The data can be downloaded or streamed to the base station for display purposes and further processing. LifeGuard measures 2 channels of ECG, respiration rate, heart rate, activity, skin temperature, SpO2, and blood pressure.	URL: http://lifeguard.stanford.edu Email: n/a Phone: 650-604-0936	12
Sensor	Intelligent Clothing	Intelligent Clothing renders obsolete unsightly and un-nerving monitoring devices in that an intensive-care-standard of monitoring can be obtained from what appears to be normal every-day underclothing. They specialize in devices intended for pediatric care.	URL: http://www.intelligentclothing.com/index.html Email: info@intelligentclothing.com Phone: 727-424-4609	13
Sensor	Philips Electronics	Philips Electronics has developed a sensor based on dry-electrode technology that can be built into common items of clothing such as bras, briefs or waist belts, Philips' wireless monitoring technology continuously monitors the wearer's body signals such as the heart activity to detect abnormal health conditions.	URL: http://www.research.philips.com/InformationCenter/Global/FNewPressRelease.asp?lArticleId=2823&lNodeId=976 Email: koen.joosse@philips.com Phone: +31 40 2743703	14

Device Type	Company	Description of Products, Services or Information Provided	Contact Information	Reference #
RFID	News&Observer Newspaper	Article looking at how RFID can be used for security measures.	URL: http://newsobserver.com/business/story/1450122p-7584688c.html Email: n/a Phone: n/a	15
MEMS	CNN	Article addressing how MEMS devices can aide healthcare professionals in detecting disease.	URL: http://www.cnn.com/2002/HEALTH/01/22/microchip.heart/ Email: n/a Phone: n/a	16
Sensor	MicroStrain	MicroStrain manufactures a variety of smart, wireless sensors and datalogger products for use in wearable and embedded devices. Focusing on data capture and transmission MicroStrain works in biomechanics and civil engineering to measure strain, orientation, temperature and acceleration.	URL: http://www.microstrain.com/wireless_sensors.htm Email: n/a Phone: 800-449-3878	17
Sensor	Intuicom	Intuicom has developed a weather sensing system that has been implemented in Oklahoma. The system is wireless with bases 60 miles apart.	URL: http://www.intuicom.com/www/solutions/env_mon/mesonet.htm Email: info@intuicom.com Phone: 303-449-4330	18
Info	Habitat Monitoring on Great Duck Island	The Great Duck Island project synthesizes cutting edge sensor technology with robust network solutions to monitor aviary habitat in a harsh environment.	URL: http://www.greatduckisland.net Email: alan.mainwaring@intel-research.net Phone: 510-495-3013	19
Info	Habitat Monitoring on Great Duck Island	The Great Duck Island project synthesizes cutting edge sensor technology with robust network solutions to monitor aviary habitat in a harsh environment.	URL: http://www.cs.berkeley.edu/~polastre/papers/wsna02.pdf Email: alan.mainwaring@intel-research.net Phone: 510-495-3013	20
Sensor	Crossbow	Crossbow specialized in the manufacturing and development of a wide array of sensors and sensor networking products.	URL: http://www.xbow.com/ Email: info@xbow.com Phone: 408-965-3300	21
Network	Automated Buildings	Article from Sensicast on how sensor networks can be utilized to maximize the performance of the buildings HVAC systems.	URL: http://www.automatedbuildings.com/news/jun04/articles/sensicast/Sereiko.htm Email: news@automatedbuildings.com Phone: n/a	22
Sensor	Environmental Sensors Inc (ESI)	ESI specializes in the design, manufacture, and distribution of environmental sensors and instruments used in the precise monitoring of water, its presence and movement. Their products suit fresh, ground and salt water applications.	URL: http://www.esica.com/index.html Email: info@esica.com Phone: 1-800-799-6324	23

Device Type	Company	Description of Products, Services or Information Provided	Contact Information	Reference #
Network	nPhase	nPhase offers M2M services tailored to monitor and manage widely dispersed machine assets on a global scale.	URL: http://www.nphase.com Email:info@nphase.com Phone: 312.664.7000 ext: 232	24
Network	The Focal Point Group	A primer on M2M technology and development, providing definitions and uses of M2M technology, as well as an overview as to where M2M is going in the future.	URL: http://m2mpoint.com/Documents/ M2M_Primer.pdf Email: n/a Phone: n/a	25
Network	Sensicast	Sensicast Systems, Inc. develops and markets low-power, battery-operable, wireless sensor network solutions for the commercial, industrial, agricultural and security industries. The company develops complete end-user solutions and also licenses its Sensicast wireless software framework to OEMs targeted at specific vertical markets.	URL: http://www.sensicast.com Email: sales@sensicast.com Phone: 781.453.2555	26
Sensor	Transducer Tech, Inc.	Transducer Tech produces gases detectors that use nanotechnology to deliver robusts capabilities in small packages. Their CO detector is the size of a remote key ring and could be tweaked to detect other chemicals and air borne particles.	URL: http://www.transducertech.com/ Email: support@transducertech.com Phone:510-791-0951	27
Sensor	Smart Sensors and Integrated Microsystems	SSIM is located in Wayne State University's Engineering Department and focuses on integrating various technological advances in useable devices and applications. Their focus is on sensors and systems that integrate sensor components.	URL: http://www.ssim.eng.wayne.edu/ Email:kabram@eng.wayne.edu Phone: 313-577-1306	29
Sensor	RAE Systems Inc (RAE)	RAE is a leading global developer and manufacturer of rapidly deployable chemical detection monitors and multi-sensor networks for homeland security and industrial applications.	URL: http://www.raesystems.com/product/ category/detail/62 Email: raesales@raesystems.com Phone:408.752.0723	31
Sensor	Foster-Miller	Foster-Miller has developed sensor technologies aimed at chemical process analysis under extreme environmental conditions of temperature and pressure. Applications include monitoring composite cure in autoclaves, measuring temperature and presence of free radicals in gas turbine engines, and identification of chemical waste and water ingress in composite bridges.	URL: http://www.foster-miller.com/ Email:n/a Phone: 781.684.4000	37

Device Type	Company	Description of Products, Services or Information Provided	Contact Information	Reference #
Network	Sandia National Labs	Article discussing how sensor networks can be utilized in homeland security efforts.	URL: http://www.sandia.gov/news-center/publications/sandia-technology/2003/st2003v5no2.pdf Email: n/a Phone: n/a	38
RFID	Psion Teklogix: White Paper on RFID	General overview of RFID white paper from Psion Teklogix	URL: http://www.psionteklogix.com/assets/downloadable/understanding_RFID_and_Associated_Applications.pdf Email: n/a Phone: n/a	48
RFID	Bearing Point: White Paper on RFID	White paper focusing on RFID in Retail	URL: http://www.bearingpoint.com/industries/consumer_and_industrial_markets/attachments/RFID_in_Retail_WP_100703.pdf Email: n/a Phone: n/a	49
RFID	Speedpass	Speedpass is an automated payment system that utilizes RFID technology. Speedpass is most popular at gas stations and some fast food chains.	URL: http://www.speedpass.com/home.jsp Email: n/a Phone: 877-733-3727	50
RFID	Philips Electronics	Philips Semiconductor partnered with automaker Toyota to develop a robust tracking system that is capable of monitoring products in the supply chain.	URL: . http://semiconductors.philips.com/markets/identification/articles/success/s48/ Email: christine.vaudet@philips.com Phone: +33 1 47 28 6608	51
RFID	RFID Journal	Article presents information on military supply chains and the integration of RFID to help manage their inventories.	URL: http://www.rfidjournal.com/article/view/883 Email: mroberti@rfidjournal.com Phone: 631-851-0325	52
RFID	RFID Journal	Informative article on using RFID to track and control inventory of medicine and equipment in medical environments.	URL: http://www.rfidjournal.com/article/view/1081 Email: mroberti@rfidjournal.com Phone: 631-851-0325	53
RFID	Wired	Article on Wal-Mart and DOD's role in moving the RFID market forward.	URL: http://www.wired.com/news/business/0,1367,61059,00.html Email: n/a Phone: n/a	55
Sensor	Power Point presentation	Power Point presentation from North Dakota Military Medical Conference presented by Joel Jorgenson, Ph.D., P.E.	URL: http://www.ndmilitarymedicalconference.org/program/Jorgenson.pdf Email: n/a Phone: n/a	57
WiFi	WiFi Alliance	Website providing information about the WiFi Alliance and the potential for WiFi based systems to aide communications between networks.	URL: http://www.wi-fi.org/OpenSection/index.asp Email: gennis@wi-fi.org Phone: 310-399-5052	49

Device Type	Company	Description of Products, Services or Information Provided	Contact Information	Reference #
Info	Global Enterprise	White paper on Wireless Local Area Networks addressing which technologies are most capable of providing robust services.	URL: http://wp.bitpipe.com/resource/org_ 1078177630_947/WhichWLANisBest.pdf Email: n/a Phone: n/a	65
Network	MobileInfo	WiFi vs. Bluetooth article comparing the strengths and weaknesses, as well as anticipated best use of both of these emerging technologies.	URL: http://www.mobileinfo.com/News_ 2003/Issue20/Forrester_WiFiBluetooth.htm Email: mobileinfo1@mobileinfo.com Phone: 905 - 881 - 8537	66
Bluetooth	HP	White paper released from Hewlett Packard on Bluetooth technology. This paper provides not only a thorough overview of Bluetooth technology but also how Bluetooth can be incorporated into multiple systems to increase interoperability between devices.	URL: http://h18000.www1.hp.com/products/ wireless/wpan/files/WhitePaper_BluetoothTe chnologyOverview-QA.pdf Email: n/a Phone: n/a	67
Bluetooth	The Official Bluetooth Website (.com)	The official Bluetooth website provides information about Bluetooth and the companies that work with this technology.	URL: http://www.bluetooth.com/ Email: n/a Phone: n/a	68
Sensor	IBM - Zurich Research Labs	IBM's Zurich Research Labs have development an unified mobile health information delivery system using existing devices and peripherals. This article provides an overview of the system.	URL: http://www.zurich.ibm.com/news/03/ mobilehealth.html Email: ews@us.ibm.com Phone: 888-839-9289	69
RFID	RFID Journal	The online resource RFID Journal's article on cell phone manufacturers integrating RFID readers into their next generation of mobile phones. This integration will facilitate the ability to make purchases using the cell phone, as well as accessing other services in a mobile environment.	URL: http://www.rfidjournal.com/article/ articleview/1020/1/1/ Email: mroberti@rfidjournal.com Phone: 631-851-0325	71
Bluetooth	Arab Com Forum & Expo	Power Point presentation on Bluetooth technology	URL: http://www.arabcom.com/pdfs/pres 2003/CETECOM.pdf Email: n/a Phone: n/a	72
Bluetooth	Ericsson	Bluetooth information on Ericsson's website provides information about Bluetooth and the companies that work with this technology.	URL: http://www.ericsson.com/bluetooth/ aboutbluet/faq/default.asp?action=show& id=16 Email: n/a Phone: n/a	73
Bluetooth	Palm Infocenter	Article on fourth generation Bluetooth technology.	URL: http://www.palminfocenter.com/view_ story.asp?ID=6872 Email: n/a Phone: n/a	74

Device Type	Company	Description of Products, Services or Information Provided	Contact Information	Reference #
ZigBee	ZigBee Alliance Website	Power Point presentation giving an overview of ZigBee technology and how it can be used to integrate systems and controls.	URL: http://www.zigbee.org/resources/documents/ZigBeeOverview4.pdf Email: n/a Phone: n/a	75
Network	Computer World magazine	Article on development of UltraWideBandwidth (UWB), seen as not only faster than Bluetooth but also capable of handling more data quicker.	URL: http://www.computerworld.com/printthis/2004/0,4814,94896,00.html Email: matthew_hamblen@computerworld.com Phone: n/a	77
Network	Sensoria	Sensoria develops sensor networks for a wide array of applications. Using embedded computing products that communicate over a wireless network, their devices support a diverse set of sensors and external interfaces, and host local and distributed applications	URL: http://www.sensoria.com/ Email:information@sensoria.com Phone:(858) 673-4460 ext. 10	78
Info	EPA	Indoor Air Quality webpage at EPA - providing an overview and links to resources.	URL: http://www.epa.gov/iaq/ Email: iaqinfo@aol.com Phone: 202-343-9370	79
Network	Sensicast	White paper from Sensicast (see above) discussing their software platform, which is a network architecture for wireless sensor networks. It is specifically designed to enable low-power wireless communication to and from inexpensive embedded devices for the creation of multi-hop networks.	URL: http://www.sensicast.com/downloads/SensiNet_Architecture_Whitepaper.pdf Email: sales@sensicast.com Phone: 781.453.2555	80
Network	University of Maryland Baltimore County	White paper on security for sensor networks identifying threats to this application class and proposing a new lightweight security protocol that operates in the base station mode of sensor communication, where the security protocol is mindful of the resource constraints of sensor networks.	URL: http://www.csee.umbc.edu/cadip/2002Symposium/sensor-ids.pdf Email: junder2@cs.umbc.edu Phone: n/a	81
Network	Harvard University's Engineering and Applied Sciences Dept.	White paper introducing CodeBlue, a wireless infrastructure intended for deployment in emergency medical care, integrating low-power, wireless vital sign sensors, PDAs, and PC-class systems.	URL: http://www.eecs.harvard.edu/~mdw/papers/codeblue-bsn04.pdf Email: n/a Phone: n/a	83
Info	Roland Piquepaille's Technology Trends	Sensors buried deep inside a glacier transmit wirelessly their observations about temperature, pressure or ice movement to a base station located on the surface, which relays the readings to a server in the UK by mobile phone.	URL: http://radio.weblogs.com/0105910/2004/05/31.html Email: n/a Phone: n/a	84

Device Type	Company	Description of Products, Services or Information Provided	Contact Information	Reference #
Sensor	College of Computing: Georgia Institute of Technology White Paper	White paper discussing the implementation of a system to monitor the Columbia River (OR) using a remote sensor network.	URL: http://www.cc.gatech.edu/~calton/ publications/mobicom-00.pdf Email: Phone:	85
Network	Dust Networks	Dust mesh networking technology is based on years of research at UC Berkeley. Their mesh network solution consists of multiple wireless communication nodes or “motes” that communicate with each other as well as your information and control systems via a central collection point or “gateway”.	URL: http://www.dust-inc.com/ applications/main.html Email: support@dustnetworks.com Phone:(510) 548-3878	86
M2M	Brookstone	Brookstone offers a desktop "ambient orb" that works utilizing M2M technology to track the stock market or the weather.	URL: http://www.brookstone.com/shop/ product.asp?product_code=373159 Email: n/a Phone:800-846-3000	87
M2M	Echelon	Echelon offers a variety of M2M produces designed to monitor elecritical usage. Echelon device networking technology enables end-users to remotely connect, monitor, control, sense, and diagnose intelligent devices.	URL: http://www.echelon.com/ Email: lonworks@echelon.com Phone: 888-324-3566	88
M2M	emWare	emWare's remote device management technology and services provide the highest-value solution for secure, scalable device management across the enterprise	URL: http://www.emware.com/ Email: n/a Phone: n/a	89
M2M	Opto 22	Opto 22 produces a broad array of reliable, flexible hardware and software products for industrial automation, remote monitoring, and data acquisition.	URL: http://www.opto22.com/ Email: sales@opto22.com Phone: (800) 321-6786	90
Sensor	SmartSignal	Partnering with Delta Air Lines, SmartSignal has deployed a monitoring system that will be installed on planes within 5 years.	URL: http://www.smartsignal.com/markets/aviation landing.asp Email: n/a Phone: 630-829-4000	91
Network	The University of Texas at Arlington	White paper on wireless sensor networks discussing the evolution of smart environments. The paper provides an overview as to the types of systems that can be integrated using wireless sensor networks and the configurations used.	URL: http://arri.uta.edu/acs/networks/ WirelessSensorNetChap04.pdf Email: lewis@uta.edu Phone: n/a	

Device Type	Company	Description of Products, Services or Information Provided	Contact Information	Reference #
RFID	AmphenolPDC	AmphenolPDC manufactures Smart Bands ®, wristbands that have RFID tags embedded in them with read/write capabilities. These bands are used in prisons, hospitals and venues where age verification is needed. PCS also provides RFID labels, key chains, smart cards and wrist tags.	URL: http://www.amphenolpcd.com/index_win.htm Email: info@amphenolpcd.com Phone: 978.532.8800	
Network	Telecommunication Networks Group Technische University at Berlin	White paper on wireless sensor networks from the Technical University of Berlin. The paper addresses the need for cooperation between developers regarding software usage and moving towards a harmonized simulation and experimental environment.	URL: http://www.tkn.tu-berlin.de/publications/papers/sensornetz_architecture.pdf	
Network	MobileIN	White paper by Stephen Dye of Signum on End-to-End Machine to Machine technology. The paper addresses the potential of M2M technology as solving telemetry problems that have hampered the development of robust systems in the past.	URL: http://www.mobilein.com/End-to-EndM2M(1).pdf Email: n/a Phone: n/a	
RFID	Skyetek	SkyeTek offers fast affordable RFID systems integration and RFID engineering design services. Custom RFID hardware and software is their specialty.	URL: http://www.skyetek.com/ Email: sales@skyetek.com Phone: 720-565-0441	
RFID	Mannings	Mannings offers Low, High, Ultra High and Read Only tags, as well as readers compatible with their tags. They specialize in supply chain controls and networking systems.	URL: http://www.manningsrfid.com/ Email: sandra@mannings.uk.com Phone: +44 (0) 1704 538202 (UK)	
RFID	Matrics	Matrics specializes in tags, readers and antennas manufactured for industry and supply chain tracking. Only Matrics tags are orientation-insensitive. Matrics' patented dual-dipole tag is the only tag that can be read at different orientations - a key factor in achieving near 100% read rates.	URL: http://www.matrics.com/ Email: n/a Phone:(301) 610-6100	
RFID	SAVI	SAVI provides market based solutions with regards to supply management and data control systems. They manufacture readers and tags, as well as producing software tools to help control data delivery through the system.	URL: http://www.savi.com/index.shtml Email: info@savi.com Phone:800.428.0554	

Device Type	Company	Description of Products, Services or Information Provided	Contact Information	Reference #
RFID	Power Paper	Power Paper is the manufacture of Motorala's BiStatix ink based antenna technology. By using carbon in their inks Power Paper is able to print micro antennas onto labels, thus enabling communication with a reader.	URL: http://www.powerpaper.com/index_u.html Email: n/a Phone: +972-3-920-4200	
Sensor	Lighthouse Worldwide Solutions, Inc.	Lighthouse Worldwide Solutions provides contamination and environmental monitoring solutions to the high tech sector. Lighthouse systems for monitoring particulates, ammonia, airborne molecular contaminants, electrostatic discharge and other environmental factors are now found in semiconductor, pharmaceutical, data storage, biotechnology and defense industry plants worldwide.	URL: http://www.golighthouse.com/default.asp Email: n/a Phone: 408- 228-9200	
Sensor	Luna Innovations	Luna Innovations offers a variety of sensor solutions, including: fiber optic cable chemical sensors with environmental and medical capabilities, as well as accelerometers.	URL: http://www.lunainnovations.com Email: solutions@lunainnovations.com Phone: 540-552-5128	
Sensor	Verhaert	Verhaert is a producer of some innovative sensors that they embed into clothing and other devices. Their sensors are capable of measuring vital signs and other physiological measures.	URL: http://www.verhaert.com/ Email: info@verhaert.com Phone: +32 3 250 14 14	
Sensor	Smartex	Smartex is a producer of woven fabrics that integrate smart materials into their construction to provide sensing capabilities. Focusing on health care, fitness and pervasive computing Smartex aims to provide materials with robust sensing and communication capabilities.	URL: http://smartex.it Email: info@smartex.it Phone: +39-050-754350	
Sensor	Advance Medical Electronic Corporation (AME)	AME is developing advanced technology for the diagnosis of sleep disorders. Prototype devices include a wearable polysomnograph. AME is also is developing the technology to enable medical devices with Bluetooth wireless connectivity. Prototype devices including an electrocardiograph, glucose meter, and weight scale are under development.	URL: http://www.ame-corp.com/ Email: thendrickson@ame-corp.com Phone: 763-463-4814 ext. 102	
Sensor	MesoSystems	MesoSystems manufactures and commercializes airborne biosafety and security tools. They make a portable air sensor that is designed to detect harmful chemicals and compounds that could be a threat to first responders. MesoSystems is also developing a BioBadge capable of detecting harmful airborne contaminates.	URL: http://www.mesosystems.com Email: n/a Phone: 505-314-8100	

Device Type	Company	Description of Products, Services or Information Provided	Contact Information	Reference #
Sensor	LabCorp	The Holter monitor is worn by the patient for 24 to 48 hours. The ECG tracing is collected in two channels and is recorded on a cassette tape. The patient completes a Patient Diary and documents significant events that occurred while wearing the monitor.	URL: http://www.labcorp.com/services/hcp/cardiovascular_disease/ambulatory_monitoring/index.html#Holter_monitoring Email: n/a Phone: 800-289-4358	
Sensor	Sensatex	SmartShirt allows the comfortable measuring and/or monitoring of individual biometric data, such as heart rate, respiration rate, body temperature, caloric burn, and provides readouts via a wristwatch, PDA, or voice. Biometric information is wirelessly transmitted to a personal computer and ultimately, the Internet	URL: http://www.sensatex.com Email: info@sensatex.com Phone: 240-644-0242	
Sensor	Digital Angel	Digital Angel makes a wristwatch device with GPS capabilities. The device is designed to monitor not only ambient air temperature, but also provide a fall alert to emergency personnel and family. The device is intended to insure peace of mind for families.	URL: http://www.digitalangel.net/consumer.asp Email: Sales@DigitalAngelCorp.com Phone: 800-328-0118	
Info	Website on Nanometer	Website that gives a detailed view of a nanometer	URL: http://www.egr.msu.edu/~mackay/nanometer/nanometer.htm Email: n/a Phone: n/a	
RFID	ZDNetUK	Primer article on RFID	URL: http://whitepapers.zdnet.co.uk/0,39025945,60090047p-39000516q,00.htm Email:n/a Phone: +44 (0) 20 7903 6800	